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Torild Alise W. Oddane

Organizational Conditions for Innovation

A Multiperspective Approach to Innovation in a Large Industrial Company

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Thesis for the degree of doctor philosophiae
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Summary

Innovation is the main condition for survival and growth of companies living in a turbulent environment with rapid changes in technology, markets, competitive environment, and customer preferences. This thesis explores innovation in a corporate setting and contributes to the understanding of how innovation can be enhanced. It is based on retrospective case studies of four research projects in a large industrial company. The research methods have mainly been open-ended semi-structured interviews and document reviews during a period of about three years.

This thesis has an exploratory character. It sets out to answer the following main question:

What are organizational conditions for innovation?

Most innovation research represents mono-disciplinary studies of one or two facets of innovation. Such approaches tend to result in a simplistic, unsatisfying view of innovation because a part of the phenomenon is viewed as the whole phenomenon. The thesis' core argument is that innovation is a multifaceted phenomenon that is too complex to be studied properly from a single disciplinary perspective. For this reason, this thesis aims to contribute to a comprehensive understanding of innovation. It aims to offer a *multiperspective* approach to innovation in terms of applying theories and perspectives from several disciplines. Emphasis is on understanding innovation as a multifaceted phenomenon consisting of facets that (for the most part) have been studied independently. These are: *Person*, i.e. individual characteristics, knowledge, and skills promoting innovation; *Press*, i.e. conditions conducive to creativity, e.g. work-environmental factors influencing creativity; *Product*, i.e. characteristics of innovations (products); *Process*, i.e. characteristics of the innovation process; and *Partnership*, i.e. characteristics of innovation as a social, collective achievement. To properly understand innovation all facets must be taken into consideration.

A major argument in this thesis is that the understanding of innovation as a multifaceted phenomenon necessitates attention to creativity. Similar to most literature on innovation, this thesis regards creativity as a prerequisite for innovation. At the same time, it confronts three widespread perspectives on creativity, claiming that these fail to recognize innovation as a complex, open-ended activity requiring continuous co-creation of knowledge in interdisciplinary, cross-organizational networks: 1) Where most theories define creativity as idea generation, this thesis defines creativity as the capacity to define and solve open-ended problems. 2) Where most perspectives of innovation view creativity as the very source of innovation only, i.e. the point of departure for the innovation journey, this thesis asserts that creativity is needed throughout the entire innovation process. 3) Where existing literature tends to portray creativity solely as an individual quality, this thesis states that creativity is *both* an individual and a collective capacity. As such, this thesis points out that innovation is a social, collective achievement dependent on the actors' capacity to play well together in a complex web of relationships.

This thesis includes a thorough literature review and a substantial analysis and discussion part that provides a broad presentation of the case material. It consists of an introductory chapter and four main parts.

Part I, Chapters 2 through 5, presents the theoretical framework that forms the basis for the analysis and discussion of my empirical data. To begin with, I state that a broad approach to innovation necessitates attention to both "innovation" and "creativity." I also argue that a well-founded understanding of innovation requires an in-depth conceptual study of these concepts and their relationship. In Chapter 2 I shed light on definitions of innovation and innovation types. Chapter 2.2 provides an overview of definitions of innovation. Observing that the requirement of novelty is a common denominator, I show that this condition is subject to great interpretative flexibility (Pinch and Bijker, 1987). I criticize perspectives insisting on *absolute* novelty (the first development or use ever), stating that *relative* novelty (novelty to a relevant social group) is a more useful criterion of innovation. Likewise, opposing definitions reflecting sole attention to either the creation or adoption of innovations, I speak in favor of a broad perspective that includes both creation and implementation of novelty. I also argue that intentionality of benefit and the involvement of open-ended tasks are hallmarks of innovation. Finally, observing that the vast majority of definitions of innovation fails to highlight the social dimension, I state that definitions of innovation should explicitly call attention to innovation as a social, collective achievement. I then propose a temporary definition of innovation as a collective, open-ended *activity*.

In Chapter 2.3 I make a thorough study of ways to distinguish radical from incremental innovation, examining a wide range of differentiation criteria. This study shows that differentiation of radical from incremental innovation is subject to great ambiguity. Neither a unified theory nor a consensual agreement of classification criteria exists. Facing this ambiguity, I explain the reasons behind my decision to turn away from my initial attention to “radical” innovations, and formulating a research topic broadening my focus to include the concept of “innovation” as a whole.

In Chapter 3 I review and discuss the concept of creativity. I highlight the *criterion problem*, that is, the question of whether creativity should be regarded as a quality of people, products, or processes (Amabile, 1983a), and I state that creativity must be viewed as a multifaceted phenomenon rather than as a single construct to be precisely defined. Inspired by the analogy between creativity and a diamond (Isaksen, 1988) and Rhodes’ (1961) finding that definitions of creativity reflect attention to four facets, I structure my review around those facets (*Person*, *Press*, *Product*, and *Process*). I argue that existing perspectives on creativity ignore the social, collective dimension of creativity, and thus introduce a fifth facet, the *Partnership* facet of creativity. Finally, I propose a temporary definition of creativity as an individual and collective *capacity*.

To complete the study of creativity and innovation, Chapter 4 investigates different ways to distinguish creativity from innovation. I criticize most of these, claiming that they reflect either the Cartesian dualism or a linear understanding of innovation. I argue that creativity is a prerequisite for innovation, that both phenomena deal with open-ended problems, and that a distinction in terms of capacity and activity appears useful. Eventually, I propose the following definitions of innovation and creativity:

Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

Creativity is the individual and collective capacity to define and solve open-ended tasks in a novel, appropriate way.

Chapters 2 through 4 lead up to Chapter 5 where the five facets introduced in Chapter 3 constitute the underlying structure of the literature review and the model that forms the basis for the analysis and discussion of my case material. In Chapter 5.2 I present my 5P model of innovation and creativity, arguing that it represents a powerful analytic tool for obtaining a comprehensive understanding of the complexity of innovation. Chapter 5.3 calls attention to the *Person* facet. I review theories on individual creativity and perspectives highlighting characteristics of key figures in innovation efforts. Chapter 5.4

presents the *Press* facet, providing an overview of work-environmental factors that influence creativity. I base this overview on the perspectives of Nonaka and Takeuchi (1995) and Amabile (2001). In Chapter 5.5 I focus on the *Product* facet, recalling main points from Chapter 2.3. Chapter 5.6 deals with the *Process* facet. Here, I first highlight the temporal dimension of innovation through an outline of the MIRP “fireworks” model (Van de Ven et al., 1999). I then call attention to organizational learning and knowledge creation, reviewing the works of Argyris and Schön (1996) and Nonaka and Takeuchi (1995), as well as perspectives on improvisation in jazz and drama. The latter contributions complement the other works by showing how people create new knowledge in highly ambiguous, uncertain, complex and uncontrollable situations. Finally, Chapter 5.7 portrays the *Partnership* facet. Here, I shed light on characteristics of innovation as a social, collective achievement from two (related) angles. First I highlight innovation as a collective, open-ended activity through a brief review of Edquist’s (1997;2005) presentation of the systems of innovation (SI) approach. Then I address creativity as a collective capacity by means of contributions highlighting various types of inter-organizational networks and by giving a brief outline of Latour (1987).

Part II, Chapters 6 and 7, presents the context of research and research methodology. Chapter 6 provides an introduction to the context of my case studies (aluminum extrusion, mathematical modeling, and pharmaceutical product development) and gives a chronological overview of the four case projects. These are the three PROSMAT Extrusion projects *Long Die Life for Hard Alloys*, *Modeling of Flow in the Bearing Channel*, and *Empirical Modeling*, and the Omacor™ project. In Chapter 7 I outline my methodological approach and discuss the trustworthiness of my study.

In Part III, Chapters 8 through 12, I analyze and discuss my data in light of the 5P diamond model of creativity and innovation presented in Part I of the thesis.

Finally, I present the thesis’ conclusions in Chapter 13 (Part IV). Chapter 13 gives an overview of the central findings of my work and provides suggestions for further research. The most original findings derived from the facet-specific analyses are that context-relevant skills and interpersonal skills are an essential part of individual creativity; that innovation calls for creativity throughout the entire process and is a prerequisite for both creation and implementation of new, appropriate products; and that subjective judgments of innovativeness in light of the incremental-radical continuum differ to a large extent. Altogether, the facet-specific findings point out the following organizational conditions for innovation: *individual creativity (task-relevant skills, creativity-relevant skills,*

interpersonal skills, task motivation); requisite variety of task-relevant skills (domain-relevant and context-relevant skills); organizational support and supervisory encouragement; autonomy; mutual subordinate-superior trust; resources; networks; power to influence critical issues; work-forms stimulating co-generative learning and a collective reflective practice; co-generative problem definition; and collective reflection on innovation labels.

My suggestions for further research call attention to the importance of gaining better insight into how implementation of research results can be encouraged, the need for a better understanding of collective interpersonal skills, and the value of increased attention to and practice of improvisation skills in organizations concerned with ways to foster innovation.

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Chapter 1 Introduction

1.1 The Research Topic

This thesis explores innovation in a corporate setting. Based on retrospective case studies of research projects in a large industrial company, I study organizational conditions for innovation.

Most innovation research represents mono-disciplinary studies of one or two facets of innovation. Such approaches tend to result in a simplistic, unsatisfying view of innovation because a part of the phenomenon is viewed as the whole phenomenon. The thesis' core argument is that innovation is a multifaceted phenomenon that is too complex to be studied properly from a single disciplinary perspective. For this reason, this thesis aims to contribute to a comprehensive understanding of innovation. It aims to offer a *multiperspective* approach to innovation in terms of applying theories and perspectives from several disciplines. Emphasis is on understanding innovation as a multifaceted phenomenon consisting of facets that (for the most part) have been studied independently. These are: *Person*, i.e. individual characteristics, knowledge, and skills promoting innovation; *Press*, i.e. conditions conducive to creativity, e.g. work-environmental factors influencing creativity; *Product*, i.e. characteristics of innovations (products); *Process*, i.e. characteristics of the innovation process; and *Partnership*, i.e. characteristics of innovation as a social, collective achievement. To properly understand innovation all facets must be taken into consideration.

A major argument in this thesis is that the understanding of innovation as a multifaceted phenomenon necessitates attention to creativity. Similar to most literature on innovation, this thesis regards creativity as a prerequisite for innovation. At the same time, it confronts three widespread perspectives on creativity, claiming that these fail to recognize innovation as a complex, open-ended activity requiring continuous co-creation of knowledge in interdisciplinary, cross-organizational networks: 1) Where most theories define creativity as idea generation, this thesis defines creativity as the capacity to define and solve open-ended problems. 2) Where most perspectives of innovation view creativity as the very source of innovation only, i.e. the point of departure for the innovation journey, this thesis asserts that creativity is needed throughout the entire innovation process. 3) Where existing literature tends to portray creativity solely as an individual quality, this thesis states that creativity is *both* an individual and a collective capacity. As such, this thesis points out that innovation is a social, collective achievement dependent on the actors' capacity to play well together in a complex web of relationships.

1.2 Background

Recognition of the need for further research on organizational knowledge creation and innovation led to the establishment of the subject area *Knowledge Network* in The Industry Innovation Fund for NTNU. In the end of 1999 I was hired as one of the PhD students who were to study conditions for knowledge creation and innovation in complex organizations. My empirical research was to be carried out in collaboration with Hydro, one of the Fund's industrial partners. I was requested to focus on how Hydro could reduce the traditional emphasis on stepwise process improvements and stage for a larger degree of radical innovations. The finalists in the newly established *Birkeland Award for Excellent Research in Norsk Hydro* appeared to be natural case projects since innovation and creativity were major criteria for the award. Thus, the idea of studying organizational conditions for radical innovations based on retrospective case studies of research projects in Hydro was the starting point for this thesis.

1.3 Why Focus on Innovation?

1.3.1 Social and Political Relevance

*…The basic economic resource…is no longer capital, nor natural resources…, nor "labor". **It is and will be knowledge**…Value is now created by "productivity" and "innovation", both applications of knowledge to work…* (Drucker, 1993, p.7)

Drucker's statement captures the significant role innovation plays for economic and social change in the long run. Innovation is crucial for long-term economic growth in the "knowledge society." Should the stream of innovation dry up, the economy will settle into a "stationary state" with little or no growth (Fagerberg, 2005). Innovative countries and regions have higher productivity and income than the less innovative ones. Likewise, innovative firms outperform their competitors, measured in terms of market share, profitability, growth or market capitalization (Tidd et al., 2001). Thus, innovation is the major condition for survival and growth of companies living in a turbulent environment with rapid changes in technology, markets, competitive environment and customer preferences (Senge, 1990; Utterback, 1994; Gibbons et al., 1994, Nonaka and Takeuchi, 1995, de Geus, 1999). Given the complexity companies face, knowledge perishes quickly, meaning the ability to learn faster than the competitors may be the only sustainable competitive advantage (Senge, 1990).

Because of the desirable consequences of innovation, policy makers and business leaders are concerned with ways in which to foster innovation (Fagerberg, 2005). Innovation policy currently attracts considerable international attention, and several countries and regions have developed strategies to stimulate economic growth and innovation.[1] For instance, the EU aims to be the most competitive and dynamic knowledge-based economy in the world within 2010; Norway aims to be one of the most innovative countries worldwide; and Trøndelag aims to be the most creative region in Europe. Accordingly, innovation, and in particular the issue of how to enhance innovation, has great social and political relevance. At the same time, there is a need for more knowledge on conditions for innovation.

1.3.2 Relevance for Earlier Research in the Field

Despite the large amount of innovation research conducted during the past fifty years, we know much less about how and why innovation occurs than what it leads to (Fagerberg, 2005). Most innovation research has focused on explaining the implementation and diffusion of already-developed innovations, and the majority of works on innovation management have called attention to antecedents (facilitators/inhibitors) or consequences (outcome) of innovation (Van de Ven et al., 1999).

Moreover, most theorizing about innovation has traditionally looked at it from an individualistic perspective, and most works on cognition and knowledge focus on individuals, not organizations (Fagerberg, 2005). During the last few decades there has been an increase in systems approaches to innovation (Edquist, 2005) and theoretical and empirical studies highlighting organizational learning and knowledge creation (e.g. Senge, 1990; Nonaka and Takeuchi, 1995; Argyris and Schön, 1996). These works point out that innovation is a *collective* achievement. This also applies to the comprehensive MIRP

[1] The Norwegian Ministry of Trade and Industry. Fra idé til verdi. Regjeringens plan for en helhetlig innovsjonspolitikk (2003); http://www.stfk.no/News.aspx?ID=63 downloaded 2006-06-19

process model of innovation (Van de Ven et al., 1999) that explains how and why innovations unfold over time. Still, although it is by now well established that innovation is an organizational phenomenon, our understanding of how knowledge and innovation operate at the organizational level is fragmentary (Fagerberg, 2005). Accordingly, there is a need for more research on innovation at the organizational level, implying that a study of organizational conditions for innovation is highly relevant.[2]

Furthermore, it is evident that the development of new knowledge on innovation requires a stronger interdisciplinary orientation. Innovation is subject to a considerable amount of research in a variety of disciplines (Grønhaug and Kaufmann, 1988; Fagerberg, 2005). However, the field is characterized by fragmentation and conceptual fuzziness. To a large extent, researchers from various disciplines focus on different aspects of innovation and use different terms in referring to what seems to be the same phenomenon (Grønhaug and Kaufmann, 1988; Wehner et al., 1991). Moreover, mono-disciplinary approaches tend to view a part of the phenomenon as the whole phenomenon, often resulting in a simplistic, one-sided view of the phenomenon under study (Isaksen, 1988; Sternberg and Lubart, 1999; Fagerberg, 2005). It follows that one obstacle to improving our understanding of innovation is that the phenomenon has been studied independently by different communities of researchers with different backgrounds. In turn, this differentiation has impeded progress in the field because researchers from the various theoretical camps have not been able to communicate effectively with one another (Wehner et al., 1991; Fagerberg, 2005).[3] Thus, to get a comprehensive understanding of innovation, it is necessary to combine insight from several disciplines. For this reason, my multiperspective approach to innovation by integrating perspectives and theories from several disciplines is relevant in terms of earlier research in the field.

1.4 Addressing the Research Question

The request to study how Hydro could stage for a larger degree of radical innovation immediately called attention to the following research topic: Development of insight into organizational conditions for radical innovation. At the same time, I found that I should make an effort to create a broad approach to innovation to overcome the limitations of the

[2] By "organizational" conditions I mean conditions pertaining to the social, coordinated interplay of people working together to accomplish tasks that are too complex for single individuals to deal with alone.

[3] According to Bolman and Deal (1991), people from different research communities impede communication either because they not try to communicate or because they misunderstand each other when they do.

traditional single-discipline approaches that have made innovation research an unproductively fractioned endeavor. Inspired by the multiperspective thinking advocated by Bolman and Deal (1987; 1991) and Morgan (1988;1997), I had the particular ambition of modelling innovation as a multifaceted phenomenon composed of facets that (for the most part) had been studied independently. So, given the opportunity to study several research projects, I aimed at developing a thorough understanding of organizational conditions for innovation by exploring what was going on in the projects, for instance: How do people actually play together? What factors facilitate and inhibit project efforts? How do single individuals contribute? What are salient characteristics of the outcome of the projects?

Still, I faced the question: Did the projects represent cases of radical innovation? Would the case studies provide knowledge on organizational conditions for radical innovation at all? A thorough conceptual study made me conclude that ”radical innovation” was subject to great ambiguity (See Chapter 2.3). Hence, I asked myself the following questions: What can be considered a proper definition of radical innovation in light of my study? How can I find out whether the case projects represent radical innovations? Following Amabile (1988; 1996), I realized that in order to determine whether the projects could be considered as cases of radical innovation, I had to rely on the subjective judgments of appropriate observers in the field, that is, those familiar with the domain in which the outcome is produced – in my case, the participants in the case projects. The reason is that it is not possible to articulate objective criteria for identifying innovations as radical. Yet, as long as there is consensus in experts' judgments of the "radicalism" of an innovation, we can reasonably accept those ratings as valid statements.[4]Accordingly, I concluded that a case project could be considered as a case of radical innovation to the extent that appropriate observers independently agreed it was a case of radical innovation. However, at the outset of my study I had no knowledge of whether any of the case projects could be considered as "radical" in light of this consensual definition. Furthermore, the great conceptual ambiguity found in the literature made me assume that judgments of the "radicalism" of the projects would reveal variance rather than consensus. Thus, it was uncertain whether any of my case projects would be regarded as cases of "radical" innovation *at all*. At the same time, I found that the case projects could be regarded as examples of "innovation" projects.[5] For these reasons, I dropped the explicit attention to "radical" innovation and consequently efforts

[4] Evidently, no innovation researcher can be considered an "expert" in all fields of endeavor, and I was definitely not an expert in the fields represented by the case projects (aluminum extrusion and pharmaceutical product development).
[5] See Chapter 2.2.3.

into developing a well-founded definition of the concept. I decided to broaden the focus to "innovation" and turn the issue of "radicalism" into a research topic.[6] I therefore reformulated the original research theme into the following topic: Development of insight into organizational conditions for innovation.

Against this background, the objective of my thesis is to gain new knowledge of organizational conditions for innovation through retrospective case studies of research projects. This objective leads to the following main research question:

What are organizational conditions for innovation?

1.5 Outline of the Thesis

This thesis is extensive, including a thorough literature review and a substantial analysis and discussion part that provides a broad presentation of the case material. It comprises Chapter 1 and four main parts.

Part I

Part I of this thesis, *Conceptualization of Innovation and Creativity*, consists of Chapters 2 through 5. It presents the theoretical framework that forms the basis for the analysis of my empirical data. In the introduction to Part I, I state that a broad approach to innovation necessitates attention to both "innovation" and "creativity". I also argue that a well-founded understanding of innovation requires an in-depth conceptual study of these concepts and their relationship.

In Chapter 2 I shed light on definitions of innovation and innovation types. Chapter 2.2 provides an overview of definitions of innovation. Observing that the requirement of novelty is a common denominator, I show that this condition is subject to great interpretative flexibility (Pinch and Bijker, 1987). I criticize perspectives insisting on *absolute* novelty (the first development or use ever), stating that *relative* novelty (novelty to a relevant social group) is a more useful criterion of innovation. Likewise, opposing definitions propagating sole attention to either the creation or adoption of innovations, I speak in favor of a broad perspective that includes emphasis on both creation and

[6] I give an account of this decision in Chapters 2.3 and 5.5.

implementation of novelty. I also argue that intentionality of benefit and the involvement of open-ended tasks are hallmarks of innovation. Finally, observing that the vast majority of definitions of innovation fails to highlight the social dimension, I state that definitions of innovation should explicitly call attention to innovation as a social, collective achievement. I then propose a temporary definition of innovation as a collective, open-ended *activity*.

In Chapter 2.3 I make a thorough study of ways to distinguish between radical and incremental innovation, examining a wide range of differentiation criteria. This study shows that differentiation of radical from incremental innovation is subject to great ambiguity. Neither a unified theory nor a consensual agreement of classification criteria exists. Facing this ambiguity, I explain the reasons behind my decision to turn away from my initial attention to “radical” innovations, and formulating a research topic broadening my focus to include the concept of “innovation” as a whole.

In Chapter 3 I review and discuss the concept of creativity. I highlight the *criterion problem*, that is, the question of whether creativity should be regarded a quality of people, products, or processes (Amabile, 1983a), and state that creativity must be viewed as a multifaceted phenomenon rather than as a single construct to be precisely defined. Inspired by the analogy between creativity and a diamond (Isaksen, 1988) and Rhodes’ (1961) finding that definitions of creativity reflect attention to four facets I structure my review around those facets (*Person*, *Press*, *Product*, and *Process)*. I argue that existing perspectives on creativity ignore the social, collective dimension of creativity and hence introduce a fifth facet, the *Partnership* facet of creativity. Finally, I propose a temporary definition of creativity as an individual and collective *capacity*.

To complete the study of creativity and innovation, Chapter 4 investigates different ways to distinguish creativity from innovation. I criticize most of these, claiming that they reflect the Cartesian dualism, or a linear understanding of innovation. I argue that creativity is a prerequisite for innovation, that both phenomena deal with open-ended problems, and that a distinction in terms of capacity and activity appears useful. Finally, I propose the following definitions of innovation and creativity:

Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

Creativity is the individual and collective capacity to define and solve open-ended tasks in a novel, appropriate way.

Chapters 2 through 4 lead up to Chapter 5 where the five facets introduced in Chapter 3 constitute the underlying structure of the literature review and the model that forms the basis for the analysis and discussion of my case material. In Chapter 5.2 I present my 5P diamond model of innovation, arguing that it represents a powerful analytic tool for obtaining a comprehensive understanding of innovation. Chapter 5.3 calls attention to the *Person* facet. I review theories on individual creativity and perspectives discussing characteristics of key figures in innovation efforts. Chapter 5.4 presents the *Press* facet, providing an overview of work-environmental factors that influence creativity. I base this overview on the perspectives of Nonaka and Takeuchi (1995) and Amabile (2001). In Chapter 5.5 I focus on the *Product* facet, recalling main points from Chapter 2.3. Chapter 5.6 deals with the *Process* facet. Here I first highlight the temporal dimension of innovation through an outline of the MIRP “fireworks” model (Van de Ven et al., 1999). Then I call attention to organizational learning and knowledge creation, reviewing the works of Argyris and Schön (1996) and Nonaka and Takeuchi (1995), as well as perspectives on improvisation in jazz and drama. The latter contributions complement the other works by showing how people create new knowledge in highly ambiguous, uncertain, complex and uncontrollable situations. Finally, Chapter 5.7 portrays the *Partnership* facet. Here I shed light on characteristics of innovation as a social, collective achievement from two (related) angles. First I highlight innovation as a collective, open-ended activity through a brief review of Edquist’s (1997; 2005) presentation of the systems of innovation (SI) approach. Then I address creativity as a collective capacity by means of contributions highlighting various types of inter-organizational networks and by giving a brief outline of Latour (1987). Chapters 5.3 through 5.7 conclude with a list of facet-specific research questions aimed at providing a sound basis for answering the thesis’ main question.

Part II

The second part of this thesis, *The Context of Research and Research Methodology*, consists of Chapters 6 and 7. Chapter 6 introduces the context of my case studies; the fields of aluminum extrusion, mathematical modeling, and pharmaceutical product development, respectively. The purpose is to give readers not familiar with these fields a rough idea of relevant concepts and topics to facilitate the reading of the analysis and discussion of my empirical data in Chapters 8 through 12. Chapter 6 also presents a chronological overview of the four case projects. In Chapter 7 I present my methodological approach and discuss the trustworthiness of my study.

Part III

In Part III of this thesis, *Analysis and Discussion*, I analyze and discuss my data in light of the 5P diamond model of innovation and creativity presented in Part I. Chapters 8 through 12 are devoted to the *Person*, *Press*, *Product*, *Process*, and *Partnership* facets, respectively. Each chapter is structured around the facet-specific research questions presented in Chapter 5.

Part IV

The final part of the thesis, *Conclusion*, consists of Chapter 13 that gives an overview of the central findings of my work. To begin with, I briefly recapitulate the main purpose of the thesis. In Chapter 13.2 I give an outline of the central findings derived from the facet-specific analyses and discussions in Part III of the thesis. Then follows a summary of the central findings in terms of a list of organizational conditions for innovation (Chapter 13.3). Finally, Chapter 13.4 presents the thesis' contributions to the literature, while Chapter 13.5 provides suggestions for further research.

Appendices A and B provide glossaries for aluminum extrusion and pharmaceutical product development, respectively, while Appendix C gives an overview of field activities discussed in Chapter 7.

Part I: Conceptualizing Innovation and Creativity

The purpose of this part is to present the theoretical framework that forms the basis for the analysis and discussion of my empirical data. Part I covers a thorough conceptual study of the concepts of innovation and creativity and the relation between these. It reviews relevant literature on innovation and creativity in light of five facets (*Person*, *Press*, *Product*, *Process*, and *Partnership*) and introduces my 5P diamond model of innovation and creativity. In Chapter 2 I shed light on definitions of innovation and innovation types. Chapter 2.2 provides an overview of definitions of innovation, while Chapter 2.3 focuses on radical and incremental innovation. In Chapter 3 I review and discuss the concept of creativity. I also introduce the *Person*, *Press*, *Process*, *Product*, and *Partnership* facets of creativity. To complete the conceptual study, Chapter 4 investigates ways to distinguish creativity from innovation. Chapters 2 through 4 lead up to Chapter 5 where the five facets introduced in Chapter 3 constitute the underlying structure of the literature and my 5P diamond model of innovation and creativity.

In the following introductory section I clarify the basis for the content and overall composition of the chapters constituting this part of the thesis. First and foremost, I state my reasons for devoting considerable space for a review and discussion of the concepts ”innovation” and ”creativity”. I also explain why I find it necessary to bring *both* concepts into focus rather than laying sole emphasis on ”innovation” - the starting point of my study reflected in the thesis' objective and research question (Ref. Chapter 1). In this connection, I stress that the headings of the first three chapters (2 What is Innovation?/3 What is Creativity?/4 What is the Relationship between Creativity and Innovation?) should not be taken as signs that I regard ”creativity” and ”innovation” as separate phenomena. The chapters represent topical ”steps” of my journey to the understanding that underlies the structure of the literature review and model presented in Chapter 5 Innovation and Creativity in Light of Five Facets: Person, Press, Product, Process, and Partnership. In brief, this understanding includes the following points:

Creativity and innovation are multifaceted phenomena
"Creativity" and "innovation" are equal terms
Creativity is a prerequisite for innovation
Creativity is the individual and collective capacity to define and solve open-ended tasks in a novel, appropriate way
Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values

As discussed in Chapter 1, the starting point for my doctoral work was the request to focus on how Hydro could stage for a larger degree of radical innovations. At the same time, my aim was to approach innovation as a multifaceted phenomenon. My research objective implied that I – a novice in the field of innovation studies – had to make myself familiar with two new concepts: "innovation" and "radical innovation".

My intention of developing a sound understanding of innovation proved to be far more demanding than expected. I soon realized that I had entered a large, complex area in which no unified theory of innovation existed. Innovations have been subject to a considerable amount of research in a variety of disciplines, among them psychology, sociology, social anthropology, economics, economic theory, engineering disciplines, geography, public policy, marketing, and corporate strategy (Grønhaug and Kaufmann, 1988). I was overwhelmed by the great variety of approaches and nodded in recognition when reading the following observation:

> *… For the researcher making first contact with the literature on innovation, the most daunting feature of it is not its size – though it is undoubtedly very large – but its sheer diversity. Work by social and occupational psychologists, personality theorists, sociologists, management scientists, and organizational behaviourists can all be found under the banner "innovation*"…(King, 1990, p. 15)

I noticed that the term "innovation" was used in many different ways that appeared to vary systematically with the level of analysis employed; the more macro the approach (e.g. societal or cultural) the more various and amorphous the usage of the term became (West and Farr, 1990). I also learned that researchers from various disciplines to a large extent stress different aspects of innovation, that main concepts partly differ across disciplines, and that definitions are neither right nor wrong, only useful to a greater or lesser extent (Grønhaug and Kaufmann, 1988). The fact that the terms "innovation" and "innovative" have come into fashion, being widely used in commercials and advertising (– and even in private Christmas cards!), adds further complexity to the matter. As von Stamm (2003, p.5) holds:

> *…Today it seems to be fashionable to call everything an 'innovation', from the redesign of packaging to the introduction of hydrogen powered cars; basically everything that used to be called 'new product development' in the past…*

Facing this complexity I asked myself: What deserves the label "innovation"? What is a proper definition in light of my study? I concluded that in order to develop a well-founded position I had to conduct a thorough literature review. I assumed that a comprehensive review of definitions of innovation could also be a useful contribution to existing innovation research, serving as a source of inspiration for reflections on the concept among researchers and business people. So, in sum, the observations and reflections referred to serve to explain the underlying purpose of the review and discussion presented in Chapter 2.2 Definitions of Innovation. In turn, this conceptual analysis led up to my temporary definition of innovation as collective activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

Furthermore, my investigation into the concept "radical innovation" revealed a great variety of definitions and ways to distinguish between different types and levels of innovation. Evidently, this finding reflected the view that categorization is essential for effective innovation management; different kinds of innovation require different management approaches (e.g. Abernathy and Clark, 1985; Leifer et al., 2000; Ørstavik et al., 2002; and Gaynor, 2002). At the same time, I noticed that several researchers regarded classification of innovation as a difficult process. Various categories overlap and distinctions are by no means exhaustive (West and Farr,1990; Gaynor, 2002). Again, I concluded that I had to conduct a conceptual study in order to reach a proper understanding of the concept "radical innovation". This conclusion was the point of departure for the review and discussion constituting Chapter 2.3 Radical and Incremental Innovation. Thus, Chapter 2 What is Innovation? comprises the overall literature review and discussion I considered necessary to develop a well- founded position regarding the ambiguous terms "innovation" and "radical innovation".

On my journey in the field of innovation I faced still more conceptual challenges. I quickly encountered the frequent phrase ”creativity and innovation” indicating that

”innovation” seemed to be inextricably linked to ”creativity” in kind of a ”salt and pepper” fashion. Why was that? What was the relationship between the concepts? I wondered. On further inquiry, the following finding tickled my curiosity: Sometimes ”creativity” and ”innovation” appeared to be synonymous terms, sometimes not. I observed that ”innovation” and ”creativity” may be considered discipline-based synonyms because different disciplines use different terms and emphasize varied aspects of what seems to be the *same* phenomenon (Grønhaug and Kaufmann, 1988; Wehner et al., 1991). Examining 100 recent doctoral dissertations on creativity, Wehner et al. (1991) found that doctorates in business tended to prefer “innovation” and studies of organizational processes, whereas doctorates in psychology used “creativity” and were mostly concerned with individual traits. Accordingly, there is much creativity research that is not recognized as such because different labels such as “aesthetics”, “entrepreneurship”, “innovation”, “invention” or “discovery” are attached to it (Kupferberg, 1996). The reason behind this is that creativity research is an interdisciplinary phenomenon (Isaksen, 1988; Wehner et al., 1991; Williams and Yang, 1999) whose delimitation of boundaries and context is subject to controversy (Bach, 1971; Isaksen, 1988; Wehner et al., 1991). Realizing that creativity research spans several contexts, levels of analysis, and conceptual labels (Grønhaug and Kaufmann, 1988; Williams and Yang, 1999; Sternberg and Lubart, 1999), I assumed that relevant “innovation research” might be hidden behind the label “creativity research”. Ergo, to fulfill my intention of a broad approach to innovation, I found that I could not ignore the concept of creativity and the field of “creativity research”. Sole attention to “innovation” could easily result in the same narrow, unsatisfying perspectives as reflected in the following fable of the blind men and the elephant:

> *…We touch different parts of the same beast and derive distorted pictures of the whole from what we know. “The elephant is like a snake” says the one who only holds its tail; “The elephant is like a wall”, says the one who touches its flanks… (*Wehner et al., 1991, p. 270*)*

Thus, the finding that “innovation” and “creativity” may be discipline-based synonyms is one reason why I decided to bring the concept of “creativity” into focus.

Similar to “innovation”, “creativity” proved to be an ambiguous term. I learned that since 1950, “creativity” has been a term of ever-increasing popularity among both academics and most people. For instance, as early as 1959 the psychological researcher I.A.Taylor found more than 100 definitions available for analysis (Bach, 1971; Isaksen, 1988). His analysis, as well as subsequent research, shows that researchers assign loose and varied meanings to "creativity". In the words of Ellen Bach (1971, p.17): "There are as many definitions of creativity as writers in the field." At the same time, "creativity" has had a strong positive charge all along, because being "creative" is attractive and prestigious (Ekvall, 1979). Actually, job advertisements and concepts such as "the creative class" (Florida, 2002; 2004), "creative industries", and "creative" qualities, suggest that "creativity" is the most desirable feature today. Therefore, I do not wonder that words such as "creativity" and "creative" have been taken into widespread use, comprising almost "everything". As Stein (1983) commented more than 20 years ago:

> *…On the contemporary scene words like creativity and creative are used with such abandon that they are beginning to lose all significance. Applied to paradigmatic shifts (Kuhn, 1970), big and little inventions, "new and improved" products, creative cookery (for good as well as for bad meals) and for creative financing (usually "questionable" deals)…*(Stein, 1983, p.1)

Taking account of the widespread use of "creativity" and the large number of definitions, I concluded that I had to conduct a thorough literature review to develop a sound understanding of "creativity". This conclusion forms the basis for Chapter 3 What is Creativity?

The study of "creativity" proved to be important in several ways. I found that it could be appropriate to define creativity as the individual and collective capacity to define and solve open-ended problems in a novel, appropriate way. Moreover, I became acquainted with the *criterion problem*[7], and I was introduced to the suggestion of drawing an analogy between the study of creativity and a diamond. This conceptual input triggered the idea of the 5P diamond model of creativity and innovation introduced in Chapter 5. Next, comparing the study of "creativity" with the foregoing analysis of "innovation", I observed several points of similarity between conceptualizations of the terms. At the same time, the studies made me realize that creativity and innovation might be regarded as different yet intertwined phenomena. In particular, the frequently used phrase "creativity and innovation" suggested that "creativity" and "innovation" appeared to be more than discipline-based synonyms. On further inquiry, I noticed that the terms often acted in concert in titles of publications in the

[7] The criterion problem concerns the question of whether creativity should be regarded a property of people, products, or processes (Amabile, 1983a).

field. For example, a search in the BIBSYS[8] database on January 19, 2005, for books containing both ”creativity” and ”innovation” in the title, resulted in 50 hits. A search for book titles containing variants represented by the trunks ”creativ?” and ”innovati?” gave 75 hits. These observations made me conclude that a proper understanding of “creativity” and “innovation” required a closer study of common ways to distinguish the terms. This conclusion underlies the literature review and discussion in Chapter 4 What is the Relationship between Creativity and Innovation? In turn, this study made me propose a distinction between innovation and creativity in terms of *activity* and *capacity*, as reflected in the following definitions:

Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

Creativity is the individual and collective capacity to define and solve open-ended tasks in a novel, appropriate way.

I also suggested that creativity should be regarded as a prerequisite for innovation throughout the entire innovation process.

So, to summarize, Chapters 2 through 4 reflect the closely related steps on my journey to a satisfactory understanding of the concepts I regard as important in light of the research question *What are organizational conditions for innovation?* Likewise, these chapters show how my specific idea of the 5P diamond model of innovation and creativity gradually emerged from my dialog with the material.

My conceptual model, comprising the five facets *Person*, *Press*, *Product*, *Process*, and *Partnership*, reflects my emphasis on understanding innovation as a multifaceted phenomenon. In this connection, my notion of the model as a model of innovation *and creativity* underscores my argument that a broad approach to innovation studies cannot ignore creativity. Ergo, even though innovation appears to be the superior phenomenon of study in light of my main research question, I regard creativity and innovation as equal terms.

[8] BIBSYS is a shared library system for all Norwegian Libraries, the National Library and a number of college and research libraries. Souce: http://www.bibsys.no/bibsys-status-e.htm Downloaded 2006-09-20

Chapter 2 What is Innovation?

2.1 Introduction

In this chapter I shed light on definitions of innovation and innovation types. The purpose is to make a thorough presentation and discussion of literature to explain the basis for my conceptualization of innovation.

Chapter 2.2 provides an overview of definitions of innovation. Observing that the requirement of novelty is a common denominator, I show that this condition is subject to great interpretative flexibility (Pinch and Bijker, 1987). Researchers propose different definitions in terms of focus of novelty, referential material, degree of novelty, and target groups. I criticize perspectives insisting on *absolute* novelty (the first development or use ever), stating that *relative* novelty (novelty to a relevant social group) is a more useful criterion of innovation. Likewise, I oppose definitions propagating sole attention to either the creation or adoption of novelty, speaking in favor of a broad perspective including both the creation and implementation of novelty. I also argue that intentionality of benefit and the involvement of open-ended tasks are hallmarks of innovation. Finally, observing that the vast majority of definitions of innovation fails to highlight the social dimension, I state that definitions of innovation should explicitly call attention to innovation as a social, collective achievement. Therefore, I propose the following temporary definition of innovation as a process: Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values. Similarly, I define an innovation project as a collective, open-ended project aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values. I argue that my case projects may be regarded as innovation projects in accordance with this definition.

Chapter 2.3 presents a review of various ways to distinguish between radical and incremental innovation. I make an in-depth study of the radical-incremental dichotomy, examining a wide range of differentiation criteria. This review provides a convincing demonstration of the complexity surrounding attempts to classify radical and incremental innovation. I conclude that neither a unified theory nor a consensual agreement of classification criteria exists. Discussing this ambiguity, I explain the reasons behind my decision to turn away from my initial attention to "radical" innovation, and formulating a research topic broadening my focus to include the concept of "innovation" as a whole.

2.2 Definitions of Innovation

2.2.1 The Requirement of Novelty

The Common Denominator of Definitions of Innovation

The word *innovation* originates from the Latin word *innovare* that means "to make something new".[9] According to Gaynor (2002), the term first appeared around 1297. The author does not provide any further information about the earliest use of the word. In contrast, Machiavelli gives a clear example in *The Prince* (first published in 1532), relating "innovation" to the introduction of changes:[10]

> …*And it ought to be remembered that there is nothing more difficult to take in hand, more perilous to conduct, or more uncertain in its success, than to take the lead in the introduction of a new order of things. Because the innovator has for enemies all those who have done well under the old conditions and lukewarm defenders in those who may do well under the new. This coolness arises partly from fear of the opponents, who have the laws on their side, and partly from the incredulity of men, who do not readily believe in new things until they have had a long experience of them*…(Machiavelli, 1990, p. 9)

The lines above reflect the common denominator of all definitions of innovation, namely the consensus that an innovation represents something *new* (Grønhaug and Kaufmann, 1988). This agreement is, among other things, reflected in dictionaries such as Stewart Clark's (2001) *Getting Your English Right.* Clark emphasizes that "new innovation" is to be avoided, because all innovations are inherently new. Yet, writers approach the novelty requirement differently, proposing different answers to questions such as "What is new?", "Compared to what is something new?", "To what extent is something new?" and "To whom is something new?". I regard the following story as an excellent point of departure for a thorough discussion of the observed variety:

[9] Aschehoug and Gyldendals Store Norske Leksikon
[10] I am grateful to West and Farr (1990) who made me aware of Machiavelli's use of the term. Information about when the "The Prince" was first published varies. I have chosen the year 1532 as indicated by http://www.the-prince-by-machiavelli.com and http://www.ilt.columbia.edu/publications/machiavelli.html (Downloaded 2004-09-21).

…Five people sit round a table in a jazz club. The first, who is making her first foray into music outside the classical repertoire, turns to her neighbour and exclaims that she has never heard such sounds before. It is amazing that performers, without a sheet of notation in sight, can spontaneously create music of this complexity at such length. The second, having led a slightly less sheltered existence, is able to point out that the theme of a well known popular song can be discerned from the underlying chord changes. But although he is acquainted with Dixieland jazz he is also new to this kind of music, and, he adds that he too is mightily impressed at how far the improvisational line departs from the original melody. The third person at the table remarks to his two companions that he has some familiarity and knowledge of the genre, and is pleased to explain to them that these performers are speaking, musically, in a shared vernacular of musical phrases, conventions, and clichés even. But he does concede that the performers do seem to be exhibiting a fair degree of originality in using these elements to construct their solos and ensembles. The fourth member of the group of listeners, overhearing this, snorts cynically and says that she heard the band play at another venue the previous week, and if she wasn't mistaken, they were playing almost identical music on that occasion. The band, she reckons, is overrehearsed and taking no risks. The fifth, nods in agreement, adding that the case is worse than that: he finds the group to be highly derivative, indeed downright plagiarizing much of its material, note for note in some parts. He recognizes passages from a record he owns of a very famous group playing the same number. Indeed, he adds dryly, it is his opinion that the bits they play best are where the performers have suffered lapses of memory and been forced to improvise! The first speaker has been listening to these exchanges with a widening smile on her face."Who cares?" she says, tapping her feet happily. "It is all new to me. I like it."… (Nicholson, 1990, p. 179.)

Absolute versus Relative Novelty of Innovation

The jazz club story shows that the jazz fans represent divergent opinions of the novelty of music, each one calling upon contrasting referential material to make their judgments. In a similar way, innovation researchers disagree on the requirement of novelty. Some stress *objective* novelty, that is, that an innovation should be objectively new (e.g. a patent). Others emphasize *subjective* novelty, that is, that an innovation should be perceived as new by individuals (Grønhaug and Kaufmann, 1988).

Rather than referring to *objective* versus *subjective* novelty I hereafter use the expressions *absolute/relative* novelty. This is because the notion of objective novelty seems to reflect the positivistically "charged" assumption that objectivity in its true sense is attainable. For instance, the Omacor™ project shows how the "objective" novelty of a patent was challenged by Hydro (Ref. Chapter 12). I define *absolute* novelty as newness with respect to a frame of reference that relevant actors consider as strict or absolute, for instance the first development or use of a product ever. The first jazz concert performed ever represents absolutely novelty in this sense. Likewise, *relative* novelty is newness with respect to various frames of references, thereby comprising the novelty assessments of all the five jazz fans previously presented. I now outline positions underscoring the requirement of *absolute* and *relative* novelty respectively.

Arguing in favor of absolute novelty, Levitt (1969) claims:

> *…Generally speaking, innovation may be viewed from at least two vantage points: (1) newness in the sense that something has never been done before and (2) newness in the sense that something has not been done before by the industry or the company now doing it. Strictly defined, innovation occurs only when something is entirely new, having never been done before…* (Levitt, 1969, p. 54)

Similarly, Becker and Whisler (1967) define innovation as the first or early use of an idea by one of a set of organizations with similar goals, that is, they emphasize novelty to the organization's environment rather than newness to the individual organization. In contrast, other researchers regard newness to an individual organization as a sufficient criterion for denoting something an innovation. Damanpour (1990) views innovation as the adoption of an idea or behavior that is new to the adopting organization. Similarly, Nord and Tucker (1987) state that innovation refers to a technology, a product, or a service being used for the first time by members of an organization irrespective of whether other organizations previously have used it. They remark that this position is somewhat problematic, though: To define innovation in terms of newness to organizations means blending the special case of the first and very early user with a far larger group of later users. The experience of being the first and only operator of a complex process is very different from that of being even the second user, because the second user can benefit from observations of the first. The first user may also have helped to educate suppliers and potential customers and hence have provided a new and perhaps more facilitative environment for the second adopters.

Considering the contrasting opinions just outlined, I argue that relative novelty is a more useful novelty requirement than absolute newness. First, the requirement of absolute novelty would have meant great difficulties in finding relevant cases that could serve as the empirical basis for my thesis. Projects involving something "entirely new" (Ref. Levitt, 1969) are quite rare (e.g. Ali, 1994; Leifer et al., 2000; Gaynor, 2002). Second, I am concerned with how people in the case projects met challenges they *perceived* as new, irrespective of whether people in other companies or other industries had dealt with the same problems before. Therefore, I consider relative novelty as the most appropriate novelty requirement of innovation.

Still, I challenge the use of "organization" as a frame of reference. Recalling the definitions suggested by Nord and Tucker (1987) and Damanpour (1990), it is not clear whether they require newness to *all* members of an organization - or to just to a smaller group or to a single individual. Rogers (1983) and Zaltman et al. (1973) provide more accurate descriptions here. Rogers (1983) defines innovation as an idea, practice, or objective that is perceived as new by an individual or other unit of adoption. Similarly, Zaltman et al. (1973) view innovation as any idea, practice, or material artifact perceived to be new by the relevant unit of adoption. These authors also claim that the adopting unit can vary from a single individual to a business company, a city, or a state legislature, implying that not all members of an organization may regard an item as an innovation.

Considering the emphasis on newness to an "organization" versus novelty to "a (relevant) unit of adoption", I argue in favor of the latter. In contrast to "organization", often connoting "company", "relevant unit" immediately reflects attention to a wide range of units such as companies, departments, and project networks. As such, the expression invites to a careful reflection on which "unit" appears as the most proper frame of reference in a given context. In this connection, I oppose the suggestion of regarding single individuals as "relevant" units (Ref. Zaltman et al., 1973; Rogers, 1983). This idea means that most phenomena are innovations; at all times someone experiences ideas, products, practices etc. for the first time. For instance, the jazz music in our story would be an innovation because it was new to the first jazz fan speaking. Taking account of the statements of the fourth and fifth listeners, the innovativeness[11] of the music may be questioned. Therefore, I argue in line with Amabile (1988) who states that a product or process is innovative to the extent that appropriate observers, i.e. those familiar with the domain in which the product or process is introduced, independently agree on it being innovative.[12] Amabile's consensual definition calls attention to important implications regarding the notion of "relevant unit" and conceptualization of innovation as a whole.

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[11] Nicholson (1990) uses the term "innovativeness" when referring to that people in different role relationships to an innovation, act, event, or attribution may use innovativeness differently as a descriptive-explanatory concept. He does not explicitly define the term. I interpret "innovativeness" as a term denoting the extent to which something is regarded as an innovation.

[12] Amabile (1983a; 1988) proposes an operational definition of creativity based on the subjective assessments of products by experts. She argues:

> *…As long as there is consensus in experts' ratings of products on creativity we can reasonably accept those ratings as valid statements. They should be more valid than any explicit definitions of creativity that we, the researchers, could provide to creativity judges (assuming that no creativity researchers could be considered an "expert" in all fields of endeavor)…* (Amabile, 1988, p.145)

First, her requirement of familiarity with the actual domain acts as a useful criterion for distinguishing relevant from irrelevant units. For instance, the first jazz fan is not an appropriate observer, whereas the last two obviously belong to the "relevant unit" of matter.[13] Second, Amabile's emphasis on consensus sheds light on the social construction of facts and artifacts. Her focus reflects Pinch and Bijker's (1987) point that a problem is defined as such only when there is a *social group* for which it constitutes a "problem". It also mirrors Pinch and Bijker's concept of *closure*, i.e. the sort of agreement in which the majority of the actors has the power to state at a certain point that a fact or artifact is finally developed. Ergo, speaking in favor of a social constructivist perspective on innovation, I argue that the phrase "relevant unit" should refer to a social *group*, not to single individuals. More specifically, I regard the phrase "relevant social group" as the most appropriate frame of reference regarding relative novelty of innovation.

So far, I have discussed the novelty requirement of innovation in light of *relative* versus *absolute* novelty. In the following I outline novelty in terms of the *creation* versus *adoption* of innovation. However, before heading towards that, I find it necessary clarify a topic tacitly introduced by the foregoing sentence, namely the product/process ambiguity of innovation.

Innovation – a Process, the Outcome of a Process, or Both?

"Innovation" may refer to a process *or* the results of a process.[14] Still, "innovation" often denotes *both* a process and a product in terms of outcome of the process. For instance, Damanpour (1990, p.126) defines innovation as "the adoption of an idea or behavior", i.e. as a *process*. At the same time, he claims that the innovation can be a new system, device, policy, process, product, or service, i.e. the outcome of a process. This process/product ambiguity can lead to confusion, as highlighted by the following question raised by the EC's Green Paper on Innovation (1995): When referring to the dissemination of innovation,

[13] Amabile's conception of "familiarity with a domain" seems to reflect the assumption that both a "relevant" domain and "familiarity with the domain" can be clearly defined. Considering the other four jazz fans at the jazz club, I find that the questions regarding domain and familiarity with domain are not necessarily straightforward issues. For instance, what is the relevant domain here? Jazz music in general? Dixieland-jazz? The particular jazz genre played at the jazz club? In any case, these suggestions clearly imply that the first jazz fan is not an appropriate observer. In contrast, the fourth and fifth listener may be denoted appropriate observers because of their expressed familiarity with the particular jazz heard (and apparently jazz music in general as well). What about the second and third jazz fan? The former is acquainted with Dixieland jazz, but not "this kind of music", meaning his appropriateness depends on choice of domain. Finally, the third listener "has some familiarity and knowledge of the genre". But does he have the sufficient degree of familiarity to be regarded an appropriate observer in Amabile's terms?

[14] For example, according to *The New Shorter Oxford English Dictionary,* innovation is: 1.The action of innovation; the introduction of a new thing, or the alteration of something established. 2. Commercially: the introduction of a new product on the market. 3. A result or product of innovation; a thing newly introduced; a change made in something; a new practice, method.

does one mean the dissemination of the process, i.e. the methods and practices which make the innovation possible, or the dissemination of the results, i.e. the new products? To avoid confusion, an appropriate use of "innovation" presupposes a clarification of the emphasis of matter. I find that "innovation process" is a useful term when focus is on the *manner* in which something new is worked on, i.e. the activities and conditions leading up to it. Likewise, I consider "innovation" or "results of an innovation process" to be beneficial terms when emphasis is on the outcome of an innovation process. Finally, in cases where both processes and their results are highlighted, "innovation" is an appropriate overall term provided the dual focus is made explicit.

From this brief outline of the process/outcome ambiguity of "innovation" I now proceed to the discussion of the novelty requirement in light of *innovation processes*.

The Creation versus Adoption of Novelty

As seen in the foregoing discussion on absolute and relative novelty, perceived newness is usually related to ideas, practices or material artifacts, i.e. *results* of prior processes. This emphasis tacitly introduced the novelty requirement reflected in the distinction between *creation* and *adoption* of novelty, i.e. newness in terms of innovation *processes* (Zaltman et al.,1973; Grønhaug and Kaufmann, 1988).[15] Several novelty assessments in the jazz club story referred to *creation* by highlighting use of familiar elements to construct fairly original solos or improvisation. In contrast, claims about downright plagiarizing of the music material called attention to *adoption* of innovation. Similarly, innovation researchers differ in their attention to the creation versus adoption of novelty.

Some researchers explain innovation as a creative process (often denoted "invention"[16]) whereby at least two existing concepts or entities are combined in some novel way to produce a configuration not previously known by the persons involved (Zaltman et al., 1973). For example, Schumpeter (1943, p.83) describes innovation as the process of *creative destruction* that "incessantly revolutionizes the economic structure from *within*,

[15] Even though I intuitively associate "adoption" with a corresponding assumption of relative novelty, I find that the *creation - adoption* distinction does not necessarily parallel the *absolute-relative* requirement of novelty. For instance, Levitt's (1969) emphasis on absolute novelty in terms of first or early *use* of an idea (and consequently not the creation of the idea) shows that "adoption of innovation" not necessarily reflects the assumption of relative novelty.

[16] Similar to "innovation", "invention" denotes both a process and a product in common parlance. For instance, where Freeman (1982) defines invention as an idea, a sketch or model for a new improved device, product, process or system (i.e. *results* of a process), Gaynor (2002) views invention as the process of taking an idea and developing into a concept that includes some new combinations of what is already known (i.e. invention *process*).

instantly destroying the old one, incessantly creating a new one." Likewise, Nicholson (1990) refers to innovation as the ongoing construction and reconstruction of meaning.

Other researchers define innovation in terms of *adoption*, i.e. the process whereby an existing innovation becomes a part of an adopter's cognitive state and behavior repertoire (Zaltman et al., 1973). Damanpour (1990) defines innovation as the adoption of an idea or behavior that is new to the adopting organization. This focus is also found in definitions referring to the "introduction", "application", or "implementation" of innovation[17] (e.g. Amabile, 1988; West and Farr, 1990; The Norwegian Ministry of Trade and Industry, 2003; The Research Council of Norway, 2003). To sum up, the views of innovation as creation thus imply that relevant actors can be innovative without adopting, while definitions stressing adoption suggest that actors can be innovative without being inventive (Zaltman et al., 1973).

I argue that definitions emphasizing either creation or adoption reflect an unproductively narrow understanding of innovation, asserting that innovation includes *both* the creation *and* adoption of novelty. Innovation is a complex activity that proceeds from the conceptualization of a new idea to a solution of a problem and then to the actual utilization of a new item of economic or social value (Myers and Marquies (1969). Innovation is not the conception of a new idea, nor the invention of a new device, nor the development of a new market: The process covers all these things acting together in an integrated fashion toward a common objective. Moreover, I claim that the creation/adoption dichotomy itself represents a great simplification. The processes of creation and adoption are not separate, but tightly intertwined, and adoption is indeed a creative process (Grønhaug and Kaufmann, 1988; Levin,1997; Aslaksen, 1999; Kanter, 1983). As a consequence, I regard the both-and position as far more useful that the simplistic either-or perspectives. The following elaborates on perspectives emphasizing innovation as a comprehensive process including both invention and adoption of novelty.

[17] I will discuss these concepts later. For the time being I will use "adoption" as a broad label to denote activities related to "introduction", "application", "implementation", and "commercialization".

2.2.2 A Broad Perspective on Innovation

Innovation as Creation plus Adoption of Novelty

Speaking in favor of a broad perspective on innovation, Kanter (1983) points out that innovation refers to the process of bringing any new problem solving idea *into use*, including the generation, acceptance, and implementation of new ideas, processes, products, and services. The OECD (1993) proposes a similar view, defining innovation as the transformation of an idea into a marketable product or service, a new or improved manufacturing or distribution process, or a new method of social service. Likewise, Holt (1988) argues that innovation is a process that covers the use of knowledge or relevant information for the creation and introduction of something new and useful.

Other researchers emphasize the importance of a broad perspective by objecting to an unbalanced focus on creation. According to Claxton (2001), innovation without effective implementation can easily lead to a succession of bright ideas that never take off and that easily leaves behind a trail of innovation fatigue or even cynicism. Tidd et al. (2001) argues that innovation is more than simply coming up with good ideas; it is the process of growing them into practice. Similarly, Freeman (1982) points out that innovation in the economic sense is accomplished with the first commercial transaction involving the new product, process, system, or device only. Moreover, Haanæs (1999; 2000) opposes the usual overemphasis on invention[18] by claiming that innovation consists of both *creation*[19] (i.e. the creation of new technologies, products, services, or working methods) and *commercialization* directed at finding ways to benefit economically or otherwise from the invention. He argues that the commercial challenge is equally important as the technical or conceptual one. Supporting this view, Gaynor (2002) underscores that the test of technological innovation is in the market place, not in the laboratory.

Von Stamm (2003) and Roberts (1987) elaborate further on the two aspects of innovation. Von Stamm defines innovation as *creativity plus (successful) implementation*, where *creativity* means coming up with ideas, while *implementation* is about putting an idea into practice, including idea selection, development, and commercialization. In a

[18] During my literature study I observed extensive attention to adoption or implementation of innovation rather than an overemphasis on invention (as seen in my previous presentation of the respective approaches). Obviously I have overlooked much of the literature Haanæs (1999) implicitly refers to. At the same time, I observe that terms such as ”commercialization” and ”implementation” most often are not included in the index list of books about innovation. Again, the explanation may be that I read ”the wrong books.” However, it’s also tempting to ask whether this observation support Haanæs’ reference to the usual overemphasis on invention because terms such as ”invention”, ”creativity”, and ”innovation” often are included in index lists.

[19] The translation of the Norwegian “nyskaping” into “creation” is mine.

similar way, Roberts (1987) describes innovation as *invention plus exploitation*. The *invention* process covers all efforts aimed at creating new ideas and getting them to work. *Exploitation* includes all stages of commercial development, application, and transfer, including the focusing of ideas or inventions towards specific objectives, evaluating those objectives, downstream transfer of research and/or development results, and eventual broad-based utilization, dissemination, and diffusion of the technology-based outcomes. As such, exploitation is everything involved in implementation or commercialization.

Roberts' (1987) definition reflects Roger's (1983) claim that the innovation development process consists of all the decisions, activities, and their impacts that occur from recognition of a need or problem, through research, development, and commercialization of an innovation, through diffusion and adoption of the innovation by the users, to its consequences. Similarly, the OECD's *Frascati Manual* (2002) views technological innovation activities as all the scientific, technological, organizational, financial, and commercial steps, including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products and processes. Nonaka and Takeuchi (1995) represent a broad perspective of innovation as well. Arguing that knowledge creation is the essence of innovation, they define organizational knowledge creation as the capability of a company as a whole to create new knowledge, disseminate it throughout the organization, and embody it in products, services, and systems.

All together, the broad perspectives outlined above underscores the view that innovation processes are complex processes reaching far beyond creation of ideas, products or services. This conceptualization has one important implication, namely that the value of innovations lies in their contributions to benefit. As such, intentionality of benefit is a criterion of innovation.

Intentionality of Benefit

Perceived usefulness is the prerequisite for the acceptance and impact of innovation (Grønhaug and Kaufmann, 1988). Where some researchers highlight several different kinds of benefits, others emphasize *economic* benefit only. West and Farr (1990) call attention to significant benefit for the individual, the group, organization, or wider society, arguing that possible benefits may be personal growth, increased satisfaction, improved group cohesiveness, better interpersonal communication, as well as productivity and economic benefit. Similarly, Haanæs (2000) describes benefit in a wide sense, indicating that companies may benefit economically or otherwise from an invention. In contrast, The Norwegian Ministry of Trade and Industry (2003) places its sole emphasis on the creation of "economic values." Likewise, The Nordic Council of Ministers (2004) claims that improved production processes, new technologies, inventions, or research results do not become innovations until they generate values added to the market.

West and Farr (1990) comment that the assumption of contributions to profits represent both a *value assumption*, that is, that the seeking of profits is in the best interests of all those affected by the innovation, and a *mistake*, since innovation may not always be economically valuable for an organization. Elaborating on the value assumption (the *pro-innovation bias*) of innovation, Nicholson (1990) calls attention to the evaluative "charge" of concepts, pointing out that value connotations can be so embedded in our usage that terms such as innovation operate as synonymous with "good" and successful consequences. As such, failed attempts to innovate may not be dignified with the title by those associated with it.

The notion of the pro-innovation bias calls attention to the view of innovation processes as social processes in which involved actors may perceive the intended results quite differently. For instance, the creation and implementation of a new production process may contribute to profits for an enterprise but simultaneously imply that several factory workers lose their jobs. Most likely, the seeking of profits in this case is not beneficial from the workers' point of view. I still regard intentionality of profit as a relevant requirement of innovation. Intentionality of profit is a major motivation for innovation, as shown in the four case projects of my study. At the same time, I speak in favor of a broad perspective on anticipated benefits because a sole emphasis on economic benefit may ignore other desired outcomes of innovation projects. For instance, from Hydro Aluminium's point of view, the PROSMAT Extrusion projects primarily aimed at the creation of economically profitable results. Simultaneously, The Research Council of Norway stressed the importance of creating industrial-academic knowledge networks of benefit for both companies and Norwegian research groups. Therefore, I argue that definitions of innovation should reflect attention to both economic and other types of anticipated benefits of innovation.[20] This

[20] This position calls attention to the relationship between innovation and change. All definitions of innovation emphasize the introduction of change or "something new." How is innovation to be distinguished from change more generally? According to West and Farr (1990), all innovation in organizational terms is change, but not all change is innovation. Unintended or undesired change, such as the necessity of cutting work time in a factory during a particularly hot summer, would not constitute innovation. Similarly, change that implies nothing new, for instance the routine layoffs of hotel staff in winter when booking rates decline, is not innovation. Nor are organizational changes that occur without intention of direct benefits innovations; they are simple adjustments in response to routine changes in internal or external

statement, in turn, implies that *appropriateness* should be considered as a hallmark characteristics of innovation in terms of the outcome of an innovation process.[21]

2.2.3 Summary Discussion - The Proposal of a Definition of Innovation

As previously indicated, activities related to the creation of ideas, products, etc. are called "invention", "creation", or "creativity". I argue in favor of using *creation* in this connection. First, I consider it to be the most proper translation of the Norwegian term "nyskaping" (the creation of something new) (Ref. Haanæs, 1999; 2000). Second, and even more importantly, I oppose von Stamm's (2003) reference to "creativity" because simplified expressions such as "innovation equals creativity plus implementation" give the naïve and erroneous impression that implementation involves no creativity. Obviously, creativity is a condition for all main activities pertaining to innovation processes. I hence define *creation* as the activity or process aimed at creating new, appropriate ideas, products, etc., arguing that "creation" and "creativity" are *not* synonyms (see further discussion in Chapter 4).

Furthermore, I state that "implementation" is a proper collective term for those activities labeled "adoption", "introduction", "application", "commercialization", and "diffusion" of innovation. First, the term "adoption" implicitly assumes innovations imported from the outside, failing to take account of internally generated innovations. As such, its usefulness is limited. In contrast, West and Farr's (1990) phrase "intentional introduction and application" appears more useful. Apparently, "introduction" includes the decision to acquire an innovation and the subsequent presentation of it to relevant social groups, while "application" refers to the efforts directed at taking the innovation into use. Still, recalling von Stamm's (2003) definition of implementation (putting ideas into practice, including idea selection, development, and commercialization), I find that "implementation" naturally

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environmental conditions. Thus, the routine hiring of new staff on the retirement of others, or promotion based strictly on length of service, would not be considered an innovation (ibid.). Therefore, West and Farr restrict innovation to intentional attempts to derive anticipated benefits from change.

Becker and Whisler (1967) represent a different view of the question of innovation and change. They distinguish organizational innovation and change in terms of the lapse of time since the first use or early use of an innovation, emphasizing the differences in costs of search and degrees of risk involved. Organizational innovation occurs when the organization is among the first to adopt, meaning the early adopting organization undergoes both innovation and change, whereas firms adopting later undergoes organizational change, but not innovation. Accordingly, Becker and Whisler implicitly assume that a given change involves an innovation process only when it occurs early in the diffusion process of an item (Zaltman et al.,1973). Following West and Farr (1990), I argue that innovation should be restricted to intentional attempts to benefit from change. Likewise, I oppose Becker and Whisler's perspective because of its underlying requirement of absolute novelty of innovation.

[21] I make a further discussion of this criterion in Chapter 3.5.4.

includes both “introduction” and “application”. For this reason, I prefer the term “implementation” to the phrase “introduction and application”. Since commercialization may be seen as an integral part of implementation (Ref. von Stamm’s definition), I similarly prefer “implementation” to “commercialization”. This choice also takes account of the fact that “implementation” rather than “commercialization” appears to be the most fruitful label for activities directed at the implementation of research results at industrial sites (Ref. the PROSMAT Extrusion projects). Moreover, despite my observation that diffusion of innovation is a particular field of innovation research (e.g. Rogers, 1983; Aslaksen, 1999), I argue in favor of viewing diffusion as an implementation activity. This is because diffusion deals with the challenge of turning an innovation into widespread use.[22] Thus, I regard “creation” and “implementation” as the most appropriate terms denoting the main activities in innovation processes.

The emphasis on main activities in innovation processes naturally point to that innovation should be defined as an *activity*. However, apart from calling attention to the content and purpose of innovation activities, the definitions reviewed in Chapter 2.2 ignore important questions concerning the nature of innovation. First, the vast majority fails to highlight the *social* dimension.[23] Evidently, the researchers proposing the definitions implicitly perceive innovation as a co-operative effort involving a larger number of individuals working together. This assumption is explicit in perspectives distinguishing creativity from innovation in terms of the individual/collective dichotomy (e.g. Becker and Whisler, 1967; Amabile, 1988; Rosenfeld and Servo, 1990; von Stamm, 2003).[24] Still, most definitions of innovation neglect people and thus the explicit attention to innovation as a social, collaborative achievement. I state that the social, collective dimension of innovation is too important to be left out of definitions of innovation. Innovation is a social, collective activity reflected in collaborative processes in which an ensemble of specialists interact, co-creating new knowledge through dialogue, negotiation, discussion, and experience sharing (Nonaka and Takeuchi, 1995; Greenwood and Levin, 1998; Korsvold, 2002). The participants are highly interdependent on another, interacting in a complex web of relationships often reaching beyond disciplinary and organizational borders (Gibbons et al.,

[22] Rogers (1983) views diffusion as one part of the innovation process, defining diffusion as the process by which an innovation is communicated through certain channels over time among members of a social system. Similarly, Holt (1988) views diffusion as the process of communication and use by which an innovation is spread from the source to potential users. Accordingly, the activities directed at spreading PROSMAT Extrusion results from pilot plants to other press plants within Hydro Aluminium represent diffusion.
[23] Nonaka and Takeuchi’s (1995) definition of organizational knowledge creation is the only exception.
[24] See Chapter 4.2.2 for further details.

1994). Innovation is also a political process involving interest articulation and struggles for power (e.g. Pinch and Bijker, 1987; Latour, 1997). Different relevant social groups interact in the same process to develop new, appropriate products and processes. The different groups attribute different meanings and interests to the products or processes under development, meaning innovation involves continuous negotiation and renegotiation among those involved in the activity. Accordingly, I state that definitions of innovation should explicitly call attention to innovation as a social, collective phenomenon. The definition proposed by Van de Ven et al. (1999) serves as a prominent example here, describing innovation as new ideas developed and implemented to achieve desired outcomes by people who engage in transactions (relationships) with others in changing institutional contexts (emphasis is mine). I hence define innovation as a *collective* activity.

Second, although some definitions discussed in Chapter 2 highlight degrees and novelty and thus implicitly the degree of difficulty associated with innovation activities, none of them specify this issue. I argue that "innovation" should be restricted to open-ended (heuristic) activities, that is, tasks that do not have a clear and straightforward path to solution (Amabile, 1983a; 1988).[25] Innovation is a highly ambiguous, uncertain, dynamic, and uncontrollable exploration into the unknown by which novelty emerges (Van de Ven et al., 1999). People are neither able to know the final destination nor able to be in control of the journey (Stacey, 1996). As such, they have to explore, experiment and play with possibilities without knowing where their queries will lead or how action will unfold. Accordingly, I define innovation as an *open-ended* activity. Based on the foregoing discussion I hence propose the following definitions of innovation as a process and outcome of a process respectively:

Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

An innovation in terms of the outcome of a collective, open-ended activity is a product or process that generates significant benefit and other values. A product or process is innovative to the extent that members of a relevant social group independently agree on it being innovative.

Accordingly, an innovation project may be defined in this way:

[25] The requirement of the involvement of open-ended tasks is discussed in further detail in Chapter 3.5.5.

An innovation project is a collective, open-ended project aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

The definitions require some final points of clarification. First, I do not consider the "creation" and "implementation" of new, appropriate products/processes as strictly separated processes where "implementation" follows "creation" in a linear manner. Evidently, something that has not been created cannot be implemented. However, my point is that innovation activities interact throughout the process, weaving a complex web of relationships (OECD, 1996). I reject the traditional linear model of innovation, arguing that it represents a simplistic view of innovation (Rosenberg, 1991). Second, I regard "products" and "processes" as broad terms. I argue that "products" can be anything produced by an organization, from aluminum sections to jazz concerts. Similarly, "processes" can include any method of production, methods of management, or services offered by the organization.[26] Third, by omitting "ideas" from the definition I aim to take account of the fact that not all ideas about "products" or "processes" are intentionally created but may result from serendipity (Robinson and Stern, 1997).

Finally, I make a comment on the question about whether my case projects can be regarded as innovation projects in accordance with the definition proposed above. In a strict sense, my case projects are R&D projects, forming only *one* part of innovation activity as a whole (OECD, 2002). At the same time, they represent an emphasis on intentional creation and implementation of new, appropriate products/processes to create significant economic and other values. Furthermore, factors such as the projects' time line, research target, and characteristics of the social, collaborative relationships (complex interdisciplinary, inter-organizational web), strongly indicates the involvement of open-ended tasks. As such, I claim that my case projects serve as examples of innovation projects.

[26] A "product" is usually conceived in its widest sense, covering all kinds of observable results arising from both thought and work processes (Ekvall, 1979; Amabile, 1988; Boden, 1999). As such, a "process" can be considered as a "product" in this sense of the word. However, I chose to refer to "innovations" as both "products" and "processes", thereby reflecting the widespread distinction between product and process innovation (e.g. Holt, 1988; Damanpour, 1987;1990; Levin et al. (1994); The European Commision's Green Paper on Innovation (EC 1995); The Research Council of Norway, 2003; The Nordic Council of Ministers, 2004). Still, this distinction is not unambiguous. The process and product aspects of innovations often merge, making it difficult to judge whether an innovation is a product or a process (Tidd et al., 2001). In addition, the judgment is context-dependent (Ørstavik, 2000; Kirkebak). For example, from a machine manufacturer's point of view, the development of a new machine is a *product* innovation. Still, a customer who makes use of the new machine to produce new products will view it as a process innovation (Kirkebak). Thus, the categorizing of innovations depends on the meaning relevant groups ascribe to them (Pinch and Bijker, 1987).

2.3 Radical and Incremental Innovation

2.3.1 Introduction to the Distinction between Incremental Versus Radical Innovation

The literature is full of attempts to classify different types and levels of innovation. This is because categorization is necessary for effective innovation management; different kinds of innovation require different management approaches (Abernathy and Clark,1985; Leifer et al., 2000; Ørstavik et al. (2002); Gaynor,2002). One of the theoretical typologies is the distinction between *incremental* versus *radical* innovation (e.g. Ettlie et al., 1984; Henderson, 1993; Lee and Na, 1994; Utterback, 1994; Levin et al., 1994; Van de Ven et al., 1999; Leifer et al.; 2000; Ørstavik et al., 2002).[27] This dualism is also reflected in dichotomies such as *normal science/scientific revolutions* (Kuhn, 1962/1970), *technological improvement/technological change* (Thulin/NOU, 1981), *routine/radical innovation* (Nord and Tucker, 1987), *conservative/radical inventions* (Hughes, 1987), *incremental improvement/technological breakthrough* innovation (Holt, 1988), *exploitation/exploration* (March, 1991), *incremental/pioneering* innovation (Ali, 1994); *single-loop/double-loop* learning (Argyris and Schön, 1996); *improvements/innovations* (Robinson and Stern, 1997); and *progressive innovation*/*radical innovation* (The Norwegian Ministry of trade and industry, 2003). The differentiation between *incremental* and *radical* innovation, and other similar dichotomies is closely related to Schumpeter's (1934; 1943) distinction between *continuous* "stationary circular flow of economic life" and *discontinuous* "economic development." Since Schumpeter's work has influenced succeeding research on innovation, I let his thoughts form the basis for the following discussion on *incremental* versus *radical* innovation.

According to Schumpeter (1934), the stationary processes of "the circular flow" are characterized by continuous adaptation in incremental steps within the same framework. The changes represent no qualitative new phenomena, but rather processes of adaptation to changes in data existing at any time. In contrast, "economic development" occurs spontaneously and discontinuously. This "revolutionary" change arises from within the system "which so displaces its equilibrium point that the new one cannot be reached from the old one by infinitesimal steps" (Schumpeter, 1934, p.64). Thus, Schumpeter's main

[27] One exception is Nelson and Winter's (1982) evolutionary perspective that stresses the long-term and progressive aspects of innovations. Defining innovation as new combinations of existing routines they concern themselves with the idea of gradual development, devoting their attention to the nature and sources of continuity in economic change.

criterion for distinguishing economic processes is the *nature* of the process, that is, either *continuous* incremental adaptation of existing phenomena or *discontinuous* change creating qualitatively new phenomena.[28]

Schumpeter (1934) identifies five groups of innovations: A new product; a new production method; a new market; a new source of supply of raw materials or semi-manufactured goods; and the new organization of any industry. Evidently, he regards novelty as a relative, rather than absolute, concept. He stresses that a new method of production does not need to be based on a new scientific discovery; it may also be found in a new way of handling a commodity commercially. Similarly, he defines a new market as one into which the particular branch of manufacture in question has not previously entered, irrespective of the market's previous existence. Likewise, a new source of supply is an innovation irrespective of whether this source already exists or whether it first has to be created. Accordingly, Schumpeter is not concerned with the technical novelty of a product or process in itself. Rather, he regards novelty to manufacturers or customers as the most salient feature of innovation. Finally, it is noteworthy that Schumpeter, despite his argument about discontinuity, claims that new combinations always must draw the necessary means of production from some old combinations: Development, thus, simply means the different employment of the economic system's existing supplies of productive means (ibid.).

2.3.2 What is the Difference between Radical and Incremental Innovation?

Common criteria for separating incremental and radical innovation are the project time line, the frequency of occurrence, objective, the nature of the process, the degree of change, impact on competence, impact on existing markets or industry, focus, risk and uncertainty/rate of predictability, success rate, potential return of investment, the scope of costs and other resources, and technical novelty (see Table 2.3.1).[29]

[28] Schumpeter (1934/43) seems to restrict the term *innovation* to the innovation *process* only, i.e. the commercial or industrial application of something new. In the following section I have chosen to let "innovation" refer to both innovation processes and the outcome of these processes.

[29] Leifer et al. (2000) present a comprehensive list of key differences between radical and incremental innovation, but only a few of these will be discussed here.

Criteria	Incremental innovation	Radical innovation	References
Project time line	**Short**	**Long**	**Levin et al. (1994); Leifer et al. (2000)**
Frequency of occurrence	**Often**	**Seldom**	**Ali (1994); Leifer et al. (2000); Gaynor (2002)**
Nature of process	**Continuous**	**Discontinuous**	**Schumpeter (1934); Utterback (1994) Leifer et al. (2000)**
Objective	**Improvement of existing products etc.**	**Creation of new products etc.**	**Henderson and Clark (1990); Ali (1994); Levin et al. (1994); Utterback (1994) Leifer et al. (2000) Gaynor (2002) Gjelsvik (2004)**
Degree of change	**Small**	**Large**	**Henderson and Clark (1990); Levin et al. (1994)**
Impact on competence	**Competence enhancing**	**Competence destroying**	**(Abernathy and Clark (1985); Tushman and Anderson (1987))[30]; Utterback (1994); Henderson (1993) Gjelsvik (2004)**
Impact on market or industry	**Expansion of existing markets**	**Creation of new markets/ transformation of existing markets/ destruction of old ones**	**Utterback (1994); Leifer et al.(2000); Gaynor (2002)**
Focus	**Exploitation**	**Exploration**	**Leifer et al. (2000)**
Risk and uncertainty	**Low**	**High**	**Zaltman et al. (1973) Ali (1994); Levin et al. (1994); Leifer et al. (2000); Ørstavik (2002) Gjelsvik (2004)**
Predictability of outcome	**High**	**Low**	**Ali et al. (1994); Levin et al. (1994); Leifer et al. (2000); Ørstavik (2002) Gjelsvik (2004)**
Success rate	**High**	**Low**	**Leifer et al. (2000); Ørstavik (2002)**
Potential return of investment	**Low**	**High**	**Ali (1994); Levin et al. (1994); Leifer et al. (2000); Ørstavik (2002)**
Costs	**Low**	**High**	**Levin et al. (1994)**
Technical novelty	**Low**	**High**	**Zaltman et al. (1973); Lee and Na (1994)**

Table 2.3.1 Summary of Key Criteria for Differentiation between Incremental and Radical Innovation

Following Schumpeter (1934), several researchers agree that *incremental innovation* is about *improvement* of something that already exists (Henderson and Clark, 1990; Ali, 1994; Levin et al., 1994; Utterback, 1994, Gaynor, 2002). In the words of Gaynor (2002, p.24),

[30] The parenthesis indicates that Abernathy and Clark (1985) and Tushman and Anderson (1987) do not explicitly refer to incremental and radical innovation.

incremental innovations comprise "the nuts and bolts kind of innovation - the modification, refinement, simplification, consolidation, and enhancement of existing products, processes, services, and production and distribution activities." Incremental innovation usually strengthens the dominance of established firms (Henderson and Clark, 1990). In contrast, *radical* innovation transforms existing markets or industries or creates new ones (Utterback, 1994; Leifer et al., 2000; Gaynor, 2002). This is because radical innovation involves the introduction of a new concept departing significantly from past practice. The more an innovation deviates from an existing alternative, the more radical it is, and the higher the risk and uncertainty associated with it is (Levin et al., 1994). As such, radical innovation implies high risk, high uncertainty and a high level of unpredictability[31] (Ali, 1994; Levin, 1994; Leifer et al, 2000; Ørstavik, 2002; Gjelsvik, 2004). More specifically, radical innovation implies high rates of *technical* uncertainty, *market* uncertainties, *organizational* uncertainties, and *resource* uncertainties (Leifer et al.,2000).[32] Obviously, resource uncertainties reflect the *risk of exploration*, i.e. the risk that innovation activities steal time, attention, and other resources from challenges related to daily operations (Haanæs,2000). It follows that radical innovation involves risky investments that, in the worst-case-scenario, mean waste of invested resources. In fact, attempts at radical innovation result in more failures than successes (Leifer et al., 2000; Ørstavik, 2002). At best, however, radical innovation results in handsome returns (e.g. Ali, 1994; Levin et al, 1994; Leifer et al., 2000; Ørstavik, 2002). Furthermore, radical innovation projects are long term projects, meaning high costs (Levin et al, 1994). Such projects usually last for ten years or more (Leifer et al., 2000). Yet, the actual project time line, and the scope of required economic resources are difficult to estimate in radical innovation ventures (Levin et al., 1994).

As opposed to radical innovation, incremental innovation usually means low risk, low uncertainty – and a high degree of predictability concerning the outcome of an innovation process (e.g. Ali, 1994; Levin et al., 1994; Leifer et al., 2000). These aspects are closely related to the scope of resources associated with incremental innovation projects. Such

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[31] Usually the terms *risk* and *uncertainty* are treated as synonymous terms in the literature. One exception is Roussel et al. (1991, p.76-77) who make a clear distinction, defining risk "a function of the probability of the desired outcome of a defined action (the uncertainty factor) and exposure (typically financial)."

[32] *Technical uncertainty* includes issues related to, among other things, the completeness and correctness of the underlying scientific knowledge, whereas *market uncertainties* concern issues about customer needs and wants. *Organizational* uncertainties comprise questions about management and organization of radical innovation projects. Finally, *resource* uncertainties concern uncertainties about financial and competencies *resources*.

projects are often short-term projects whose project time line ranges from six months to two years (Leifer et al., 2000). In addition, incremental innovations are associated with low costs, but simultaneously with low potential return on investment (Levin et al., 1994). In other words, the previous review provides an explanation for the frequency of occurrence of incremental and radical innovation respectively: “Risky” radical innovation seldom occurs, while “predictable” incremental innovation is the most frequent type of innovation (e.g. Ali, 1994; Leifer et al., 2000; Gaynor, 2002).

Nevertheless, several researchers call attention to the long-term risk resulting from a one-sided emphasis on incremental innovation (Henderson and Clark, 1990; Utterback, 1994; Leifer et al., 2000). For instance, Utterback (1994) observes that the entry and exit of firms from an industry parallels product innovation within that industry. Accordingly, radical innovation often creates difficulties for established firms, but can form the basis for the successful entry of new firms or even a redefinition of the industry (Henderson and Clark, 1990).

In the following I call attention to criteria such as technical novelty and the impact of innovation on competence and market issues. Researchers view the relative importance of these criteria differently. What some researchers view as the decisive criterion for “radical” innovation, others regard as less important. For instance, Zaltman et al. (1973) define *radicalness* as the combination of an innovation’s novelty and risk; the most radical innovation is both novel and highly risky. Lee and Na (1994) view *technical novelty* (as seen from the point of an individual company) as the main criterion for the differentiation of incremental and radical innovation. In sharp contrast, Leifer et al. (2000) highlight the commercial performance of an innovation, arguing that radical innovation is driven by *new value added to the market place* rather than by technical novelty or newness to the firm: The most salient feature of radical innovations is that they “create such a dramatic change in products, processes, or services that they transform existing markets or industries, or create new ones.” (Leifer et al., 2000, p.5)

Arguing in line with Leifer et al. (2000), Gaynor (2002) points out that radical innovation involves the introduction of new products or services that develop into major new businesses or spawn new industries, or that cause significant change in an entire industry and tend to create new values. Thus, both Leifer et al.(2000) and Gaynor (2002) look to effects within the market place. Leifer and his co-writers also present a description of the features of the “new” products or services, defining *radical innovation* as a product, process, or service with either an entirely new set of performance features or familiar features that offer potential for significant improvements in performance (five times or greater) or reduction of cost (30 percent or greater).

Speaking in line with Leifer et al. (2000) and Gaynor (2002), Utterback (1994) regards issues related to the *impact* of radical innovation as a more prominent feature than technical novelty. At the same time, he highlights the Schumpeterian argument of innovation as new combinations, claiming that innovation often draws from existing technologies and models for its application, but uses these elements creatively in combination with new ones to form a uniquely different product.[33] Yet, Utterback's main point is that radical innovation creates new businesses, transforming or destroying existing ones, thereby following Schumpeter's idea of creative destruction. He also calls attention to innovations in terms of their relationship to existing business and technical capabilities, stating that "discontinuous change or radical innovation" is change "that sweeps away much of a firm's existing investment in technical skills and knowledge, designs, production technique, plant and equipment" (Utterback, 1994, p.200). As such, Utterback (1994) reflects the thinking of Abernathy and Clark (1985), Tushman and Anderson (1987), and Henderson (1993) who distinguish between *competence enhancing* and *competence destroying* technological shifts or innovations respectively. For instance, Henderson (1993) defines *incremental* innovation as routine; it is a predictable change that is a logical extension of existing knowledge. In contrast, *radical innovation* is competence-destroying, requiring the firm to process quite different kinds of information.

Henderson's (1993) definition of *radical* innovation emphasizing competence destruction equals Gaynor's (2002) description of *discontinuous* innovation.
Gaynor claims that discontinuous innovation tends to make the skills of engineers, scientists, accountants, patent attorneys, and other professionals obsolete unless they recognize the impact of the diminished value of their knowledge and experience. Thus, where Henderson views competence destruction as the salient feature of *radical* innovation, Gaynor regards competence destruction as the decisive criterion for *discontinuous* innovation. Likewise, where Gaynor separates between discontinuous and radical innovation, emphasizing the effects within the firm and market place respectively,

[33] For instance, the first Remington typewriter machine was a synthesis of many existing technologies and mechanical elements in widespread use at the time Clockwork suggested the idea of escapement, i.e. moving the carriage one letter at a time. The keys and their connecting arms were adaptations of the telegraph key. A sewing machine pedal returned the carriage, and the piano suggested a model for the free-swinging arms and hammers that struck the letter to the paper (Utterback, 1994).

Utterback (1994) regards discontinuous and radical innovation as synonymous terms, stressing the competence destroying effect.[34]

Tushman and Anderson (1987), on the other hand, distinguish between competence enhancing and competence destroying *discontinuous* technological change. Ergo, conceptualizations on *radical*, *competence destroying*, and *discontinuous* innovation indeed differ.

Also Leifer et al. (2000) view incremental and radical innovation in terms of competence. These authors call attention to the competence requirement of incremental and radical innovation. Referring to March (1991), they claim that *incremental innovation* is about exploitation of old certainties, that is, refinement, choice, production, efficiency, selection, implementation, and execution, while *radical innovation* requires exploration competencies involving search, variation, risk taking, experimentation, play, flexibility, discovery, and innovation. Yet, Leifer and his co-writers do not regard competence issues as the decisive criterion for separating incremental from radical innovation.[35]

Summing up the foregoing review, I find that researchers use a variety of criteria to distinguish radical from incremental innovation (Ref. Table 2.3.1). Where some focus on one single criterion, others highlight a group of features. At the same time, opinions on the relative importance of the respective criteria differ. Thus, differentiation of radical from incremental innovation is subject to great ambiguity.

Other aspects add further complexity to the matter. First of all, the validity of several criteria may be questioned. For instance, in contrast to the long-term/short-term distinction previously outlined (Ref. Table 2.3.1), Gaynor (2002) states that incremental innovation projects can be short- *or* long term. In addition, as opposed to the assumption that incremental innovation means a limited potential return on investment, several researchers claim that incremental innovation may have significant economic consequences as well (e.g. Myers and Marquis,1969; Henderson and Clark, 1990; Henderson,1993; Robinson and Stern, 1997; Leifer et al.,2000).[36] In turn, the latter statement indicates that an incremental innovation project may actually result in radical innovation if the feature improvements in existing products or services lead to the significant performance or cost improvement

[34] Likewise, Rosenbloom and Christensen (1998) argue that an innovation is radical when it introduces a discontinuity in the way that performance is evaluated. Radical innovations disrupt the established trajectories of technical advantages.

[35] As discussed earlier, the definition proposed by Leifer et al. (2000) is driven by new value added to the market place.

[36] For example, Robinson and Stern (1997) note that incremental improvements resulted in enormous cost savings for American Airlines. Similarly, Leifer et al. (2000) claim that effective incremental innovation and dramatic improvements in operating efficiency were the two keys to the success of Asian firms during the 1980s.

associated with radical innovation projects (Ref. Leifer et al., 2000). Ørstavik (2000) remarks that relatively moderate changes to something existing may have radical consequences far beyond the initial intentions or expectations. The possibility that incremental innovation projects may produce radical innovation shows that categorization of innovation is not about differentiation criteria only. The temporal dimension is also important. Most often this aspect is not explicit, causing uncertainty regarding interpretation of criteria: Do criteria refer to the potential or intended effects of innovation projects (*the future*), the impact of current innovation projects (*present time*), the consequences of already-developed innovations introduced by firms outside the company or industry (*the past*) – or a combination?

Finally, attempts to differentiate radical from incremental innovation are based on the assumption that innovations may be divided into neat dichotomies. The notion that "radicality" depends on the degree of deviation from existing practice (Ref. Levin et al.,1994) calls attention to that the radical-incremental dichotomy represents a simplified distinction. It ignores the fact that innovations may be more or less radical and thus may represent combinations such as partly competence enhancing/partly competence destroying innovations (Abernathy and Clark, 1985; Henderson and Clark, 1990).

2.3.3 Summary Discussion

Chapter 2.3.2 demonstrates that differentiation of radical from incremental innovation is subject to great ambiguity. Neither a unified theory nor a consensual agreement of classification criteria exists. The distinction between incremental and radical innovation is associated with no less than fourteen different criteria covering characteristics of the innovation process, impact of the innovation process, characteristics of innovation (as a result of an innovation process), and the impact of the innovation (as a result). Recalling the argument that categorization is a prerequisite for effective innovation management, it is evident that classification is an ambiguous tool: Which of the definitions reviewed in Chapter 2.3.2 should form the basis for managers' attempt to attain radical innovation? Utterback's (1994) definition? The one proposed by Leifer et al. (2000)? - Or maybe a different one all together? This problem naturally calls attention to the following questions: What is a proper definition of radical innovation in light of my study? Which criteria do I consider as hallmark characteristics of "radical" innovation in light of my definition of "innovation" proposed in Chapter 2.2?

Studying Table 2.3.1 I find that *high risk and uncertainty*, *low predictability of outcome*, and the need for *exploration* clearly reflects my emphasis on innovation as an *open-ended* activity, that is, an activity dealing with difficult tasks that do not have a clear and straightforward path to solution (Ref. Chapter 2.2.3). Accordingly, these criteria should be considered as salient features of "innovation" by itself and not as characteristics pertaining to "radical" innovation only. What features of "radical" innovation should be considered as decisive criteria for separating "radical" innovation from innovation, then? Indeed, following Leifer et al. (2000, p.5) I could argue that the most salient feature of radical innovations is that they create such a dramatic change in products, processes, or services that they transform existing markets or industries, or create new ones. That is, I could define radical innovation as a product, process, or service with either an entirely new set of performance features, or familiar features that offer potential for significant improvements in performance (five times or greater) or reduction of cost (30 percent or greater). Still, the strong emphasis on new value added to the market place is not necessarily appropriate in light of my case projects. It is relevant only to the extent that at least one of my case projects offer examples of innovations adding new value to the market place in the way proposed by Leifer et al. (2000). I don't know whether any of my case projects represent "radical" innovations in terms of this criterion. To find out about this I must rely on the subjective judgments of appropriate observers in the field, that is, those familiar with the domain in which the outcome is produced (Amabile, 1988;1996) – in my case, project participants.[37] I assert that a case project can be considered as an example of "radical" innovation in terms of the criterion in question to the extent that project members independently agree on it offering potential for significant improvements in performance (five times or greater) or reduction of cost (30 percent or greater). The point is: *It is not possible to articulate objective criteria for identifying something as a "radical" innovation*. Therefore, the use of consensual definitions based on the subjective judgments of experts in the field represent a sound strategy in empirical research (Amabile, 1988;1996). As long as there is consensus in experts' judgments of the "radicalism" on innovations, we can reasonably accept those ratings as valid statements.[38] Such consensual definitions should be more valid than any explicit definitions of radical innovation than innovation researchers

[37] Ref Chapter 2.2.1

[38] See Chapter 3.5.2 for a further discussion regarding subjective judgments of appropriate observers.

could provide. Evidently, no innovation researchers can be considered “experts” in all fields of endeavor, and I am definitely not an expert in the fields represented by the case projects (aluminum extrusion and pharmaceutical product development). Thus, my position is that an innovation is radical to the extent that appropriate observers independently agree on it being radical.

Accordingly, to find out whether any of the case projects provide examples of radical innovation in accordance with the definition proposed by Leifer et al. (2000)I necessarily have study how project participants perceive the projects in light of value added to the market place. However, I can’t take a consensual agreement for granted, meaning I have no guarantee that any of the case projects can be considered as examples of “radical” innovation. In fact, I do not know whether the project members associate the case projects with “radical” innovation *at all.* Neither do I know whether project participants independently would agree when asked to make judgments about the “radicalism” of the projects nor do I know which criteria they would base their assessments on. Moreover, the great conceptual ambiguity revealed in Chapter 2.3.2 make me assume that judgments of “radicalism” would reveal variance rather than consensus; when innovation labels mean different things to researchers, they probably mean different things to industrial people as well.[39]

Thus, I conclude that it is uncertain whether any of my case projects would be regarded as cases of “radical” innovation”. For this reason, it is also questionable whether they are appropriate cases for the study of conditions for “radical” innovation. On the other hand, I maintain that the case projects can be regarded as examples of innovation projects in light of my definition proposed in Chapter 2.2. I hence drop the explicit attention to “radical” innovation and efforts into developing a well-founded definition of the concept. I broaden my focus to “innovation” defined in terms of an open-ended activity reflecting several characteristics usually associated with “radical” innovation. In addition, I decide to turn the issue of “radicalism” into a research topic (See Chapter 5.5) and study how members of the case projects assess project results in terms of the “radical-incremental” dimension.

[39] The findings presented in Chapter 10 strongly support this assumption, revealing considerable disagreement on innovativeness in light of the incremental-radical dimension of innovation.

Chapter 3 What is Creativity?

3.1 Introduction

In this chapter I review and discuss the concept of creativity. The purpose is to make a thorough presentation of relevant literature in order to clarify the basis for my understanding of the phenomenon. Chapter 3.2 gives an introduction to the field of creativity research and conceptualizations of creativity. It shows that the concepts of creativity research and creativity are subject to extensive interpretative flexibility. Claiming that creativity should be viewed as a multifaceted phenomenon rather than a precisely defined concept, I discuss creativity in light of "the four P's of creativity" (Rhodes, 1961) - *Person*, *Product*, *Press*, and *Process* - in Chapters 3.3 to 3.7. I argue that novelty, appropriateness, and the involvement of an open-ended problem are criteria of creative products. Moreover, observing that several perspectives associate creativity with the mere generation of ideas, creative thinking/cognitive processes, and problem solving, I state that creativity should be perceived as a as a broader process that also includes work aimed at gaining social acceptance of creative contributions, problem definition, and creative action. Finally, I conclude that existing perspectives of creativity reflect the simplistic and erroneous assumption that creativity is merely an individual capacity, failing to recognize creativity as a social, collective achievement. I therefore introduce a fifth P of creativity, *Partnership*, and suggest that creativity can be defined as *the individual and collective capacity to define and solve open-ended problems in a novel, appropriate way*.

3.2 Creativity – a Complex Multifaceted Phenomenon

3.2.1 Creativity Research – an Ambiguous Field of Study

Creativity is a subject that has fascinated people for millennia. This fascination has led to considerable research and writing, most of which has focused on the personal characteristics of people who have been exceptionally creative (Robinson and Stern, 1997). Yet, creativity research is a relatively young discipline. Most researchers who provide a historical perspective of creativity research highlight the year 1950 as a significant starting point (Isaksen, 1988). It was during this year that the American psychologist J.P.Guilford used his inaugural presidential address to the *American Psychological Association* (*APA*) to argue that the field of psychology should make it a priority to understand the phenomenon of creativity (Guilford, 1950; Ekvall, 1979; Isaksen, 1988; Robinson and Stern, 1997; Sternberg and Lubart, 1999). Guilford's speech was a landmark in the study of creativity (Robinson and Stern, 1997), formally introducing experimental creativity research (Bach, 1971).[40] Likely, the concept "creativity" appeared for the first time during this address (Ekvall, 1979).[41] Until then, researchers had used terms such as "imagination," "originality," "genius," "talent," "freedom," and "individuality" to conceptualize creativity. Since 1950, however, "creativity" has been a term of ever-increasing popularity among both academics and most people.[42] As early as 1959, the psychological researcher I.A.Taylor found more than 100 definitions available for analysis (Bach, 1971; Isaksen, 1988). Taylor's analysis and subsequent research shows that "creativity" is subject to extensive interpretative flexibility.[43] Thus, conceptualization of "creativity", and in consequence, "creativity research" is a complex issue. It is difficult to have a clear idea of what the boundaries of creativity research are, and what belongs to that particular category. There are several factors to consider here. First, researchers have adopted the term from common parlance and have been unwilling to give up this lack of precision in favor of more accurate definitions. As such, lots of research has been designated to be creativity research without further delimitation of its boundaries and content (Isaksen, 1988). Second, creativity research is an interdisciplinary phenomenon (Isaksen, 1988; Wehner et al., 1991;

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[40] Guildford pointed out that researchers had neglected the study of creativity. He backed up his claim by stating that only 186 out of 121 000 titles listed in Psychological Abstracts had anything to do with creativity (Guildford, 1950). By 1960, ten years later, about the same numbers of papers were appearing in print each year (Robinson and Stern, 1997). From the late 1960s until 1991, almost 9000 references have been added to the literature, and at present the development of the field can only be seen as explosive (Albert and Runco, 1999).

[41] Since I believed that "creativity" was an "old" term used by most people, I was surprised by Ekvall's (1979) assumption. For instance, the English poet Chaucer (1340?-1400) - "The Father of English Poetry" (ref. Aschehoug og Gyldendals Store Norske Leksikon)- used the word "create" as early as 1393 (Albert and Runco, 1999). Likewise, the term "creative" appeared in, among other things, the phrase "creative imagination" as early as 1730 (ibid.). Glancing through some of my English-Norwegian dictionaries from the early 1980s I found "create", "creation", "creative", "creator" as well as "creatress" (!), but no references to the noun "creativity". Accordingly, this observation may be an indication that Ekvall's assumption is plausible.

[42] A search for "creative", "creativity", "creative class", "creative industry", and "creative region" at www.google.com on March 16, 2006 resulted in the following number of hits, echoing the great interest in "creative" issues: "Creative": approximately 697 000 000 ; "creativity": approximately 151 000 000; "creative class": approximately 676 000; "creative industry": 830

[43] At the same time, "creativity" has all along had a strong positive charge; to be "creative" is attractive and prestigious. (Ekvall,1979). Ekvall (1979) remarks that "creativity" apparently has taken over the shining position "intelligence" used to have because of the latter's increasing association with negatively charged terms such as bureaucracy, race to succeed, emotional insensibility, and technocracy. In contrast, "creativity" is an optimistic word expressing hope for the better.

Williams and Yang, 1999), meaning much creativity research is not recognized as such because different labels such as “aesthetics,” “entrepreneurship,” “innovation,” “invention,” or “discovery” are attached to it (Kupferberg, 1996). Third, creativity research spans several contexts and levels of analysis (Grønhaug and Kaufmann, 1988; Wehner et al., 1991, Williams and Yang, 1999; Sternberg and Lubart, 1999). Fourth, the fact that researchers *within* specific disciplines, in particular the field of psychology, approach creativity differently adds further complexity to the matter. Sternberg and Lubart (1999) present seven approaches used to understand creativity within the field of psychology. I now make a brief outline of these in order to provide for an elaborate understanding of the difficulties involved in attempts to define and assess “creativity.”

The *mystical* approaches to creativity regard it as a spiritual process that cannot be scientifically investigated. The creative person is seen as an empty vessel that a divine being would fill with inspiration. The individual will then pour out the inspired ideas, forming an otherworldly product. The *pragmatic* approaches, in contrast, are primarily concerned with the encouragement and development of creativity, whereas *psychodynamic* perspectives view creativity as a result of tensions between conscious reality and unconscious drives.[44] Case studies of eminent creators such as Michelangelo and Einstein have been used to support these ideas. Criticizing this methodological approach, Guilford in his APA address proposed that creativity could be studied in everyday subjects and with a *psychometric* approach, using paper- and pencil tasks. Many researchers have adopted Guilford’s suggestion, and divergent-thinking tasks are main-instruments for measuring creative thinking, comparing people on a standard “creativity” scale. The *cognitive* approaches seek to understand the mental representations and processes underlying creative thought, covering studies with both human subjects and computer simulations of creative thought. The *social-personality* approach, which has developed parallel to the cognitive approach, studies individuals in context, focusing on personality variables, motivational variables, and socio-cultural environment as sources of creativity. Finally, the more recent *confluence approaches* assume that multiple components must converge for creativity to occur. These theories utilize various multidisciplinary approaches to creativity and combine some of the elements that derive from uniperspective views.

[44] Freud is perhaps the foremost proponent of this approach. According to Sternberg and Lubart (1999), Freud proposed that writers and artists produce creative work as a way to express their unconscious wishes in a publicly acceptable fashion. Later other researchers have introduced the concepts of adaptive regression and elaboration (primary and secondary processes) as well as the emphasis on pre-consciousness (ibid.).

Sternberg and Lubart (1999) argue in favor of the confluence approach. They state that unidisciplinary approaches to creativity have tended to view a part of the phenomenon as the whole phenomenon, often resulting in a narrow, unsatisfying vision of creativity.[45] Following these authors, I claim that creativity should been conceptualized as a multifaceted phenomenon. This position requires a clarification of the concept of creativity. I now shed light on definitions of "creativity," highlighting attempts to solve the *criterion problem,* i.e. the question: Is creativity a property of people, products, or processes?

3.2.2 Creativity Research - a Diamond

Amabile (1983a) states that creativity researchers are often accused of not knowing what they are talking about. She points out that the definition and assessment of creativity has long been a subject of disagreement and dissatisfaction among psychologists, creating a criterion problem that researchers have tried to solve in various ways. Some propose that creativity can be identified with particular, specifiable features of products, persons, or processes, while others suggest that creativity should be defined by the quality of the response that a product elicits from an observer. Other groups of researchers assume different kinds of creativity such as scientific, musical, artistic, and verbal. Still others argue that creativity cannot be defined – that it is unknown and unknowable (ibid.) (Ref. the mystical approach). In addition, there are those who reject the idea of crisp definitions in favor of emphasizing various characteristics or aspects of creativity (e.g. Bach, 1971; Isaksen, 1988; Sternberg and Lubart, 1999). Following the latter approach, I find that creativity should be conceptualized as a multifaceted phenomenon rather than as a single construct to be precisely defined. As Isaksen (1988, p.177) states:

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[45] Similar arguments are given by, among others, Wehner et al. (1991) and Csikszentmihalyi (1999). Sternberg and Lubart's (1999) main argument is that creativity has been a neglected research topic because of the following reasons:

1. The origins of the study of creativity were based in a tradition of mysticism and spirituality that has seemed indifferent and possibly run counter to the scientific spirit.
2. Pragmatic approaches to creativity have given some the impression that the study of creativity is driven by a kind of commercialism that, while it may be successful in its own way, lacks a basis in psychological theory and verification through psychological research.
3. Early work on creativity was theoretically and methodologically adrift from the mainstream of scientific psychology, resulting in creativity sometimes being seen as peripheral to the central concerns of the field of psychology as a whole.
4. Problems with the definition of and criteria for creativity caused research difficulties. Paper-and pencil-tests resolved some of these problems but led to criticisms that the phenomenon had been trivialized.
5. Single approaches have tended to view creativity as an extraordinary result of ordinary structures or processes, so that it has not always seemed necessary to have any separate study of creativity. In effect, creativity has been subsumed under these approaches, as a special case of what is already being studied.
6. Unidisciplinary approaches to creativity have tended to view a part of the phenomenon (e.g. the cognitive process of creativity, the personality traits of creative persons) as the whole phenomenon, often resulting in a narrow, unsatisfying vision of creativity.

> *…The study of creativity, rather than being exact science, appears to be like a diamond. It is certainly worthwhile, and you can see the entire jewel, or you can focus on one of its many facets. When your attention is directed at only one of the facets, care must be taken to avoid the tendency to forget that you are only looking at one part and not the whole. Real value, operationally, occurs when all facets are taken into consideration…*

I now present some multifaceted approaches to creativity as an introduction to a closer examination of the various facets. Arguing that the core of creativity lies in perception and in the ability to make an original change of perspective, Darsø (2001) calls attention to five characteristics of creativity. First, creativity presupposes knowledge. It is the surprise, the departure from the expected, that creates the fruitful accident, and there are neither surprises without expectations, nor expectations without knowledge. Second, creativity is closely related to cognitive processes. It involves finding new solutions to old problems, combining things in new ways or seeing things in a different perspective. Third, creativity is related to emotions, expressed in art. When expressed in art, creativity also incorporates an aesthetic feature. Fourth, creativity involves activity, the root of creation. The activity can be physical or mental, but it is hard work. Finally, novelty is a major aspect of creativity. Creation often involves the combination of known elements to form something new, ranging from a ”little different” to ”radically new”. Thus, Darsø's (2001) list indirectly points out persons (knowledge, emotions), processes (cognitive processes, activity), and products (novelty, originality, the element of surprise, aesthetic value) as facets of creativity.

Like Darsø (2001), Ekvall (1979) emphasizes the composite nature of creativity, calling attention to three connotations of "creativity". First, creativity is associated with problem solving reflected in three types of definitions highlighting particular, specifiable features of the creative product, the creative person, or the creative process respectively. Second, creativity is used in connection with discussions on art and artistic work. A painting, a poem, or a musical composition is regarded creative when it expresses the creator's ideas, thoughts, impressions, and emotions in a genuine and original way. Finally, creativity may denote a lifestyle or an attitude towards the environment and towards oneself, for instance openness to new impulses, spontaneity, and self-actualization.

The perspectives of Darsø (2001) and Ekvall (1979) reflect the findings of Rhodes (1961). Based on an analysis of 56 definitions of creativity he reported:[46]

[46]Rhodes collected forty definitions of creativity and sixteen of imagination (Rhodes, 1961, p. 306)

> *…as I inspected my collection I observed that the definitions are not mutually exclusive. They overlap and intertwine. When analyzed, as through a prism, the content of the definitions form four strands. Each strand has unique identity academically, but only in unity do the four strands operate functionally…(Rhodes, 1961, p. 307)*

The four strands Rhodes discussed included information about the personality, intellect, traits, attitudes, values, and behavior (PERSON); the stages of thinking people go through when overcoming an obstacle or achieving an outcome that is both novel and useful (PROCESS); the relationship between people and their environment, the situation conducive to creativity (PRESS); and the characteristics of artifacts of new thoughts and ideas, inventions, designs, or systems (PRODUCT). These four strands - or the four "Ps" of creativity as Rhodes called them - operates as identifiers of some key components of the larger, more complex, concept of creativity (Isaksen, 1988).

Rhodes' classification scheme has been used extensively, providing a frame of reference for the study of creativity. Inspired by this scheme, I let the four Ps of creativity form the underlying structure of the remaining part of the chapter. Adopting this approach I was faced with the criterion problem, because several definitions include more than one P. The following review should therefore be read as a pragmatic analytic approach rather than as a clear categorization of creativity definitions.

3.3 The Creative Person

3.3.1 Creativity as the Ability to Produce New and Useful Work

Researchers who view creativity as a property of people tend to focus on individual differences in people's creativity or on distinctive characteristics of creative people (Mayer, 1999).[47] For instance, Guilford (1950) defined creativity as a set of personality traits that are characteristic of creative people, claiming that:

> *…In its narrow sense creativity refers to the abilities that are most characteristic of creative people. Creative abilities determine whether the individual has the power to exhibit creative behavior to a noteworthy degree. Whether or not the individual who has the requisite abilities will actually produce results of a creative nature will depend on his motivational and temperamental traits…Creative personality is then*

[47] The trait approach to creativity, i.e. the attempt to precisely define the personality differences between creative and non-creative individuals has guided most empirical research on creativity (Amabile,1983a/b).

> *a matter of those patterns of traits that are characteristic of creative persons…* (Guilford, 1950, p. 444)

Guilford (1959) hypothesized that creative persons are *divergent* thinkers, i.e. they are able to produce many original and different ideas, as opposed to *convergent* thinkers who are oriented towards a single "correct" answer. His assumptions are reflected in definitions highlighting creativity as the ability to generate ideas, in particular new and/or useful ideas[48] (e.g. Haefele, 1962; Bach, 1971; Vernon, 1989; Rosenfeld and Servo, 1990; Burnside, 1990; Sternberg and Lubart, 1999; Byrd and Brown, 2003; von Stamm, 2003). Thus, according to this position, the ability to produce work that is perceived as new, original, and valuable distinguish creative people from other people, calling attention to the following questions: Is a "creative personality" similar to "talent" and "genius"? And: Is creativity an innate ability, meaning that the distinction between "creative people" and "non-creative people" is meaningful?[49]

[48] According to Brown (1989), Guildford and others came to focus on fluency and flexibility, and to a lesser extent on novelty. The novelty requirement and other requirements of creativity will be discussed in Chapter 3.5 The Creative Product.

[49] Another relevant issue here is the question of creativity versus intelligence. Are "creativity" and "intelligence" basically the same things, or are they not? If not, how are they related, if at all? Despite much research, psychologists still have not reached a consensus on the nature of the relation between creativity and intelligence, not even on exactly what these constructs are (Sternberg and O'Hara, 1999). Five answers, each supported by some evidence, have been proposed: 1) Creativity is a subset of intelligence 2) Intelligence is a subset of creativity 3) Creativity and intelligence are overlapping sets
4) Creativity and intelligence are essentially the same thing (coincident sets) and 5) Creativity and intelligence bear no relation at all to each other (ibid.). In his APA address Guildford gave rise to the creativity-intelligence controversy by objecting the traditional assumption that intelligence tests also measured creative potential (Brown, 1989; Robinson and Stern, 1997). He argued that abilities tapped by standard intelligence tests (*convergent* thinking), were relatively unimportant for creative behavior and that those underlying creativity (*divergent* thinking), were not tapped by intelligence tests (Guildford, 1950; Brown, 1989). As such, he rejected the view of creativity and intelligence as coincident sets, thinking of creativity as a subset of intelligence. Nevertheless, the most conventional view seems to be that of overlapping sets, meaning that intelligence and creativity overlap in some respects, but not in others (Haensly and Reynolds, 1989; Sternberg and O'Hara, 1999). In particular, researchers call attention to the "threshold effect" (Amabile, 1983a; Robinson and Stern, 1997; Sternberg and O'Hara; Plucker and Renzulli; 1999). According to this theory, a person's creativity increases with intelligence up to a certain point. But once people have enough intelligence to function in their work, this relationship no longer holds; one person is just as likely as another to be creative in that setting. Thus, a minimum of intelligence is required for an individual to exhibit creative problem solving behaviors. Empirical evidence for the threshold effects ranges from enthusiastic support to qualified reserve to refutation and rejection (Plucker and Renzulli, 1999). Nevertheless, I support the threshold effect theory and the view of creativity and intelligence as overlapping sets. This is because I find Amabile's (1983a/b; 1988) componential framework as a plausible answer to the question. According to this model, creative ability requires some minimum level of intelligence because intelligence is presumably directly related to the acquisition of *domain-relevant skills* and the application of *creativity-relevant skills*, i.e. two of the three main components of creativity. However, traditional intelligence tests do not assess other factors necessary for creativity such as *task motivation* (the third component of creativity) or personality dispositions conducive to deep levels of concentration or uninhibited risk-taking. Therefore, I consider intelligence as a necessary, but not sufficient contributing factor to creativity.

3.3.2 The Creative Personality versus Talent and Genius

Both "talent" and "genius" have been used interchangeably with "creativity". Several researchers claim that creativity should be distinguished from terms traditionally associated with creativity. *Talent* is skill that differs in the different sciences and in the arts (Ekvall, 1979; Vernon, 1989), but an unusual talent in a domain is not equal to creative abilities (Ekvall, 1979). For instance, many talented musicians with high technical skills never compose their own music or make genuine personal interpretations of written music. Their skills are limited to brilliant technical reproductions of music. As such, those musicians are talented, but not creative. However, creative performance presupposes talent, meaning talent is a necessary, but not sufficient, condition for creativity within a domain (Ekvall, 1979; Amabile, 1983a/b; 1988). Accordingly, "creativity" should not be confused with "talent."

Directing the attention towards the term "genius," Vernon (1989, p.94) argues that genius is virtually identical with very high creative abilities, "but one cannot specify *how* high." His claim seems to reflect the assumption that "genius" would have been an appropriate synonym for "creativity" provided the existence of a creativity scale with a clear demarcation between "genius" and "highly creative person". I reject the idea of regarding creativity as an absolute quantity of which high levels indicate "genius". I also argue that the very term "genius" should be avoided due to its association with the widely held stereotype of a creative person ("the lonely heroic inventor"). The extraordinary achievements of the great inventors have led us to overlook both the immeasurably greater number and impact of innovations made in corporate settings (Robinson and Stern, 1997).

3.3.3 Creativity – an Ability of the Gifted Few or Most People?

As previously indicated, the view that creativity is a dichotomous trait (either people are creative or they are not) is tacit in much creativity literature (Amabile, 1983a). Several researchers point out that much of this work implicitly assumes that creative persons are born with characteristics that differentiate them from non-creative persons (e.g. Amabile, 1983a; Stein, 1983; Robinson and Stern, 1997).[50] In contrast to the dichotomous position, other researchers believe that *all* people have, to a higher or lesser degree, the potential to

[50] Evidently, the *mystical*, *psychodynamic*, and *psychometric* approaches (Ref. Sternberg and Lubart, 1999) are based on this assumption.

be creative. Amabile (1988) assumes that it is at least theoretically possible for anyone with normal cognitive abilities to produce creative work in a domain. Robinson and Stern's (1997) work suggests that this assumption is not only a theoretical possibility; it is an empirical fact: The vast majority of unplanned creative acts in today's companies are brought about by people that no one – including themselves – previously thought of as particularly creative. Accordingly, a company can never know in advance who will be involved in a creative act, what it will be, when it will occur, or how it will occur, the authors claim, proposing the *No-Preconceptions Principle* of corporate creativity:

> *…A company's creativity is limited to the same extent that it acts on preconceptions about who will be creative, what they will do, and when and how they will do it…* (Robinson and Stern, 1997, p.20)

Ergo, the real leverage for corporate creativity does not lie in strategies based on identifying creative people, but in promoting creativity from all employees (ibid.).

Following Amabile (1988) and Robinson and Stern (1997), I argue that all people have the potential to be creative. I also claim that the individual trait approach to creativity has serious shortcomings. Within studies of intrapersonal characteristics there has been an implicit concern with "genetic" factors to the neglect of contributions from learning and the social environment (Amabile, 1983a). As such, sole attention to the creative person has excluded "creative situations," i.e. circumstances conducive to creativity (ibid.). Accordingly, the *Person* facet represents an important, but not sufficient contribution to the understanding of creativity.

3.4 The Creative Press

In response to the shortcomings of the individual approach to creativity, researchers have begun to examine creativity from a more systems-oriented perspective, emphasizing the context in which creativity occurs. Systems approaches provide a conceptualization of the multiple factors that influence creative performance within the context of an individual's social and emotional world (Williams and Yang, 1999). For instance, Amabile (1983a/b; 1988) speaks in favor of a social-psychological componential model covering *domain-relevant skills*, *creativity-relevant skills*, and *task motivation.*[51] In a similar way,

[51] Amabile's work on the social psychology of creativity is considered as an academic door opener to other systems approaches within creativity research of which Csikszentmihalyi is a major proponent (Plucker and Renzulli, 1999).

Csikszentmihalyi (1999) views creativity as the result of a dynamic interaction between the *creative individual*, the *domain* in which he or she works, and the set of judges (or *field*) that assess the quality of works that have been executed. In the following, I outline how Amabile's framework captures contextual factors.

By linking creativity to a domain, Amabile (1983a/b; 1988) (as well as Csikszentmihalyi (1999)) challenges the *domain-general view*, i.e. the classical understanding of creativity as a general characteristic applicable to most situations (Mayer, 1999). Amabile states that *domain-relevant skills*, including knowledge about a domain, technical skills, and special domain-relevant "talent", is a necessary component of creativity. As Martindale (1989, p. 213) puts it: "One cannot think of a creative idea about physics if one does not know anything about physics…to be a creative composer, one needs not only ability for creative thinking but also musical talent." Ergo, creativity is partially *domain-specific*. In turn, this implies that *learning* contributes to individual creativity. Domain-relevant skills depend on formal and informal education as well as innate cognitive abilities, innate perceptual skills, and motor skills (Amabile, 1983a; 1988). The learning factor is also valid for *creativity-relevant skills*, i.e. an appropriate cognitive style, implicit or explicit knowledge of heuristics for generating novel ideas, and a working style conducive to creativity. Such skills depend on training, experience in idea generation, and personality characteristics. As such, learning fosters individual creativity in terms of stimulating domain and creativity-relevant skills.

Still, Amabile (1983a; 1988) regards *task motivation* as the most important component of creativity. Task motivation represents the motivational variables that determine an individual's approach to a given task. No amount of skill in the domain or in methods of creative thinking can compensate for a lack of appropriate motivation to do an activity. But, to some extent, a high degree of proper motivation can make up for a deficiency of domain-relevant skills or creativity-relevant skills. Task motivation may be the easiest component to address in attempts to stimulate creativity, since this component depends strongly on the work environment. Accordingly, a work environment that promotes task motivation is essential for creative productivity (ibid.).

Taking account of the contextual factors just outlined, I oppose the view of creativity as a fixed innate quantity. Rather I consider creativity as a *quality* that is influenced by both internal and external determinants. As Amabile (1983b, p.358) holds, "creativity is best conceptualized not as a personality trait or a general ability but as a *behavior* resulting from particular constellations or personal characteristics, cognitive abilities, and social environments" (Emphasis is mine). In turn, this position implies that creativity test scores do not represent a valid indication of "creative" real-life accomplishments. Creativity tests measure what a person is at a specified point of time, but not what he or she may become in a proper environment (Kupferberg, 1996).[52]

3.5 The Creative Product

3.5.1 The Creative Product – a Favorable Starting Point for Creativity Research

Several researchers point out that analysis of creative products forms the basis for all studies of creativity, providing external criteria to which researchers can compare other methods of measuring creativity to establish validity (Ekvall, 1979; Plucker and Renzulli, 1999). No matter what the actual research focus is – the creative personality, the creative process, or environmental conditions – the creative product is important, meaning product definitions are superior to the other types of creativity definitions, Ekvall (1979) states, adding:

> *…If the researcher is interested in the creative thinking process, how creative combinations and associations arise, then he has to study the combinations as such to judge whether he really studies a creative process or not. If he aims at finding out about the creative personality, then he has to know for sure that he studies and describes creative people. How can he recognize such persons without an investigation into their products such as proposals, problem solutions, poems, drawings…? If he wants to study the impact of how environmental factors influence idea production, then he needs to observe the idea production…*(Ekvall, 1979, p. 10)[53]

In contrast, Bach (1971) points out that a creative product does not express individual creativity. The industrial division of labor implies that some individuals take part in the creative process, i.e. the generation of ideas, while others work on the result of the process, i.e. the implementation of ideas. Since the latter group only reproduces the ideas of the former, the creative product does not reflect creativity. I object Bach's claim because it assumes a neat division between idea creation and implementation and a corresponding distinction between *creative* and *reproducing* people. My point is that a "creative product,"

[52] Although some studies suggest that certain creativity tests assess qualities that correspond to real-word creative performance, the construct validity of many tests have been seriously questioned (Amabile, 1983a).
[53] My translation into English.

irrespective of whether it is an "innovation" (Ref. Chapter 2.2) or a "creative idea," expresses creativity.

What then is a "creative product"? A "product" is usually conceived in its widest sense, covering all kinds of observable results arising from both thought and work processes (Ekvall, 1979; Amabile, 1988; Boden, 1999). A concept, a drawing, a chemical formula, a recipe, a tool, or even an orally presented proposal for a new working method, is a "product" in this sense of the word (Ekvall, 1979). Furthermore, the term "creative" calls attention to the criteria of "creative" products. "Creativity" researchers (like "innovation" researchers, ref. Chapter 2.2) agree that *novelty* is the basic property of creative products (ibid.). When it comes to the interpretation of "novelty," however, creativity definitions reveal the same variance as found for definitions of innovation in Chapter 2.2. The distinction between *historical* (H) and *personal* (P) creativity, where novelty is defined with reference to the whole of human history versus the previous ideas of the individual concerned[54] (Boden, 1999), is similar to the absolute/relative novelty dimension discussed earlier. This also applies to *alpha* and *beta* creativity (Bach, 1971). *Beta* creativity refers to the novelty assessments that a person makes of his/her products with reference to the products he/she usually produces, while *alpha* creativity refers to the assessments other people make of a person's achievement with reference to other people, ideas, or products within a given context in one's age.

Since the perceptions of the novelty requirement of creativity parallel those previously highlighted for "innovation," I will not repeat this discussion here. Rather I elaborate on the requirement of relative novelty and the issue of judgments made by members of relevant social groups.

3.5.2 An Elaboration on the Requirement of Relative Novelty and Judgments of Relevant Social Groups

Alpha and beta creativity sometimes differ, in particular when people propose quite unconventional thoughts (Bach, 1971). Several researchers claim that accept by contemporaries presupposes moderate deviations from conventional thinking (Kuhn, 1962/1970; Bach, 1971; Amabile, 1988; Nickerson, 1999). For instance, scientific revolutions are characterized by intense fights between the supporters of a new paradigm

[54] H-creativity presupposes P-creativity, for if someone has a historical novel idea, then it must be new to that person as well as to others (Boden, 1999).

and defenders of the old until the former group wins the battle (Kuhn, 1962/1970). As Amabile (1988, p.146) holds, “It is well known that the most creative work in any field is often ignored or ridiculed until enough time has passed that people can understand it.” How applicable are then the judgments of products made by a relevant social group of contemporaries?

Bach (1971) rejects the idea of contemporary judgment, leaving this job to posterity. Partly agreeing, Amabile (1988) emphasizes that her consensual definition cannot be used effectively at the frontiers of any field. There is often no consensual agreement on such products because there are no experts suitable to judge these works; the works essentially define their own new field. Only with the passage of time can such pioneering products or ideas be judged on creativity.

I find that Bach (1971) and Amabile (1988) reflect certain problematic assumptions. First, the requirement of a time lag between the first introduction and judgments of products (either “all” or just the “pioneering” ones), presupposes that judges at all times can separate “worthy post-pioneering” candidates from “yet too young” ones. Second, this idea suggests that future judgments of contemporary products are more “correct” than assessments made in one’s age. I argue that judgment of novelty, as well as other criteria of creativity, is *always* difficult because it is subject to interpretative flexibility (Pinch and Bijker, 1987). Relevant social groups do not possess objective evaluation standards. Rather their judgments rely on past experience, training, cultural biases, current trends, personal values, and idiosyncratic preferences (Csikszentmihalyi, 1999). Thus, whether an idea or product is creative or not does not depend on its own qualities, but on the effect it is able to produce in others who are exposed to it. Accordingly, the assumption of an easily identifiable “ideal” point of time for creativity judgments is highly questionable. A creativity judgment made at one point of time is neither less nor more correct than previous or later ones; at most it is *different*. Third, Amabile (1988) and Bach (1971) seem to view lack of consensual agreement as a sign of truly “revolutionary” products. Finally, Amabile apparently thinks that “pioneering” products represent complete breaks with the past, meaning that contemporary experts are not qualified to make assessments at the frontiers of any field. I don’t necessarily consider lack of consensual agreement of products as a sign of a “revolutionary” product or vice versa. I state that even products that do not depart too greatly from prevailing ones, may be subject to strong disagreement concerning the novelty aspect. For instance, people who emphasize continuity may propose that a given product is not creative due to its connection to existing products. I also claim that contemporary experts are qualified for making judgments at the frontiers of their field. First, new products represent new combinations of existing products. Even the most original or novel products or ideas that have been widely recognized as unusually creative or revolutionary, have not represented complete breaks with the past but have built upon preceding products and ideas (Nickerson, 1999). Second, irrespective of a field's age, the use of expert judges is not without problems (Plucker and Renzulli, 1999). The determination of the necessary level of expertise for judges depends on a variety of factors, including the skills of the subjects, the target domain, and the purpose of the assessments. In addition, experts who can judge their own products effectively do not necessarily possess the ability to evaluate the creative products of other individuals. Accordingly, the assessments of expert judges are never "perfect."

3.5.3 Originality

Creativity definitions often reflect the requirement of originality of ideas or products. Most researchers seem to view originality as synonymous with, or as an aspect of, novelty. I speak in favor of this position. At the same time, I find that discussions on "originality" highlight other aspects of the novelty criterion than the ones that have been outlined so far. Therefore, I now make a brief presentation of this concept.

Generally, there are two definitions of "originality". Originality may refer to the first appearance, character, or parts of something when it began to exist, or when it was first made or thought of.[55] Accordingly, originality may mean *absolute novelty* or *historical creativity*, as discussed earlier. Originality may also mean unusualness in terms of statistical infrequency and unpredictability (Csikszentmihalyi, 1999).[56] For instance, originality may be defined as the ability to perceive remote associations, generate responses rated as clever, or produce responses of low frequency in the population (Prentky, 1989). Hence, because

[55] Collins COBUILD English Language Dictionary

[56] Emphasizing the personal inner sources of spontaneous creation, Nachmanovitch (1990), in contrast, claims that:

> …*Originality does not mean being unlike the past or unlike the present; it means being the origin, acting out of your own center. Out of your spontaneous heart you may do something reminiscent of the very old, and it will be original because it will be yours*…(Nachmanovitch, 1990, p. 179)

of its unusualness, a product may cause surprise (Amabile, 1983a[57]). Bruner (1962) defines creativity in terms of the response that creative products elicit from observers; a creative product is anything that produces *effective surprise* in the observer.

Considering originality in terms of unusualness and Bruner's (1962) attention to surprise, I find both to represent reasonable requirements of creative products. Still, I choose to view *novelty* as the superior criterion including the various aspects of originality outlined here. I also regard novelty as one of three major criteria for creativity, as will be outlined next.

3.5.4 Appropriateness

Several researchers claim that novelty (or originality) is a necessary, but not sufficient, criterion of creativity. In particular, they emphasize the requirement of appropriateness or value (e.g. Haefele, 1962; Kaufmann, 1988; Amabile, 1988; Brown, 1989; Martindale 1999; Boden, 1999; Gruber and Wallace, 1999; Sutton, 2001). As Kaufmann (1988, p. 91) holds:

> *…The weird ideas of a psychotic person may rank high in originality and novelty, but we would hardly regard them as creative…a thought product also has to satisfy the criterion of having some* ***use*** *or* ***value****. This requirement may be fulfilled in the way of functional use, as in technical inventions, or in aesthetic value, as in artistic productions…*

Speaking in line with the former, Brown (1989, p.11) claims that ”appropriateness is a crucial conjoint criterion to unusualness”, stating that a product must fit the demands of the situation and the needs of the creator. With complex products, the individual parts must also form a cohesive whole. Likewise, Amabile (1988) argues that a product cannot be merely bizarre; it must be appropriate to the requirements of the task at hand. Therefore, I argue that novelty and appropriateness-/value/use are both necessary criteria of creativity. In this connection, I will use ”appropriate” as an overall term for the requirement that

[57] Amabile (1983a) refers to Jackson and Messick (1965): Jackson, P. and Messick, S. The Person, the Product and the Response: Conceptual Problems in the Assessment of Creativity. *Journal of Personality*, 1965, 33, 309-329. According to Amabile (1983 p. 29), these authors suggest that judgments of outstanding creativity are composed of four aesthetic responses occurring together: 1) *Surprise* is the aesthetic response to unusualness in a product, judged against norms for such products; 2) *Satisfaction* is the response to appropriateness in a product, judged within the context of the work; 3) *Stimulation* is the response to transformation in the product, evidence that the product breaks away from the constraints of the situation as typically conceived; and 4) *Savoring* is the response to condensation in a product, the judged summary power or ability of the product to condense a great deal of intellectual or emotional meaning in a concise and elegant way. Nevertheless, Amabile comments that there has been little empirical work on Jackson and Messick's scheme, or, in fact, any other framework for understanding subjective judgments of creativity.

creative product must the useful or valuable in some way or another. Yet, novelty and appropriateness are not sufficient criteria. Creativity should also be limited to open-ended tasks.

3.5.5 Open- Ended Tasks

Several researchers emphasizing the requirement of novelty and appropriateness also state that creativity should be constrained to difficult tasks or problems (e.g. Haefele, 1962; Amabile, 1983a/1988; Gruber and Wallace, 1999). Gruber and Wallace (1999) highlight difficulty through their criteria of *purpose*, i.e. that creative products are the results of purposeful behavior, and *duration*, meaning that creative people take on hard projects lasting for some time. Without the constraints of novelty, appropriateness, purpose, and duration, creativity might not be so difficult to produce. Part of the difficulty of achieving a creative outcome arises from the need to make it compatible with human purposes and with the society and culture within which the work takes place.

Likewise, Amabile (1983a; 1988) claims that one cannot talk of creativity when a task is *algorithmic*, i.e. has a clear and straightforward path to solution.[58] Therefore, a product or idea is creative to the extent that it is both a novel and appropriate response to an *open-ended* (*heuristic*) task, i.e. a task that does not have a ready identifiable path to solution (Amabile, 1988). The solution to open-ended tasks is created by means of *heuristic* rules of thumb or incomplete guidelines. Furthermore, where algorithmic tasks by definition have a clearly identified goal, heuristic tasks may or may not have clearly defined goals. Often, heuristic tasks neither have clearly defined solutions nor goals, and it is part of the problem solvers' tasks to find them (ibid.). Amabile (1983a) proposes the following example to illustrate the distinction between algorithmic and heuristic tasks:

> *...If a chemist applied, step by step, well-known synthesis chains for producing a new hydrocarbon complex, that synthesis would not be considered creative according to this conceptual definition, even if it led to a product that was novel (had not been synthesized before) and appropriate (had the properties required by the problem). Only if this chemist had to develop an algorithm for the synthesis could the result be called creative. Similarly, an artist who followed the algorithm "paint pictures of different sorts of children with large sad eyes, using dark-toned*

[58] According to Amabile (1983a), *algorithmic tasks* are those for which an algorithm exists, meaning that the tasks have a clear and straightforward path to solution. An algorithm is a complete mechanical rule for solving a problem or dealing with a situation.

> *backgrounds" would not be producing creative paintings, even if each painting were unique and technically perfect...*(Amabile, 1983a, p.33)

Amabile (1983a) states that the differentiation between algorithmic and heuristic tasks depends on the particular goal and the level of the knowledge of the performer in question. If an algorithm for task solution exists but the individual has no knowledge of it, the task can be considered heuristic for that individual. Following Amabile (1983a), I argue that a creative product is a novel and appropriate response to an *open-ended* (heuristic) task.

Thus, to sum up, I find that *novelty*, *appropriateness*, and the involvement of an *open-ended (heuristic) task*, form the sufficient criteria of a creative product. Similarly, I agree that individual knowledge determines whether a task should be considered algorithmic or heuristic. I also claim that a task is open-ended to the extent that members of a project team independently agree it is open-ended.

3.6 The Creative Process

3.6.1 Creativity as the Production of Novel and Appropriate Work

Many process definitions of creativity reflect the person and product definitions presented earlier by calling attention to the production of novel and appropriate work (e.g. Dowd, 1989; Vernon, 1989; Burnside, 1990; Boden, 1999). Others call attention to the *nature* of the creative process, pointing out that creativity means making new combinations of existing material (Harding, 1962; Stein, 1962; Dowd, 1989; Bundy, 2002). I now give an outline of contributions focusing on creativity as a mental process.[59]

3.6.2 Creativity as a Thought Process

According to Lumsden (1999), the creative process consists of those mental events by which an organism intentionally goes beyond its prior experience to a novel and appropriate outcome. Kay (1994) describes creativity as the mental processes that lead to solutions, ideas, conceptualizations, artistic forms, theories or products that are unique and novel. Torrance (1962), who calls attention to *creative thinking*, defines creativity as the process of forming ideas or hypotheses, testing hypotheses, and communicating the results.

[59] For reasons of simplicity, I will here refer to the creative process as an overall thought process, thereby paying little attention to the various cognitive processes that are involved.

Creativity involves "adventurous thinking, getting away from the main track, breaking out of the mold" (Torrance, 1962, p. 32). Similarly, Newell et al. (1962) and Kaufmann (1988) state that creative thinking is unconventional in the sense that it requires modification or rejection of previously accepted ideas.

Kupferberg (1996) claims that creative chaos is a prerequisite for invention in project work. Because of this, he defines creativity as a learning process involving much problem formulation and a high risk of failure. At the same time, he regards creativity as a "thought play" closely related to the "pretending" play of children. This play gives people the chance to act in total absence of extrinsic constraints and stimulate their imagination. As such, creativity is basically a mood – a *playful mood* – promoting the development of new ideas and the capacity to make one's way out of the chaos. Kupferberg emphasizes that creativity is not merely about idea generation. Creativity also involves the work aimed at gaining social acceptance of new ideas. Similarly, Stein (1962) states:

> *…The fact that the individual has completed his work does not mean that the total creative process is at an end. To complete the creative process the final product…needs to be presented to and accepted by a group of significant others…* (Stein, 1962, p. 90)

Following Kupferberg (1996) and Stein (1962), I argue that the creative process involves more than mere transformation of existing material into new, appropriate combinations.

3.6.3 Creativity as Problem Solving

Several researchers point out the close connection between creative thinking and problem solving (e.g. Newell et al., 1962; Kaufmann, 1988; Bundy, 2002; Mumford, 1994). For instance, Newell et al. (1962) state that creative activity appears to be a special class of problem solving activity characterized by a novel and valuable thought product, unconventional thinking, persistence, and difficulty in problem formulation. Taking account of my argument that creativity deals with heuristic tasks, I now elaborate on the concept of open-ended problems and issues related to the problem context.

First of all, what is a "problem"? Most definitions emphasize that people have a problem when they have a goal but is uncertain as to what series of action they should perform to reach it (Kaufmann, 1988). In addition, they usually reflect the assumption that a problem arises when someone is confronted with a difficulty. The notion of a *performance gap*, i.e. the difference between the executives' criteria of satisfaction and the actual performance of the organization (Damanpour, 1990), is a relevant example here. Kaufmann (1988) argues that this kind of definition is too narrow in limiting problems to the situation where the individual is set over against a presented difficulty. The difficulty is often the result of comparing an existing situation with a *future*, *imagined* state of affairs that constitutes a desirable goal for problem solving. For this reason, Kaufmann defines a problem as a *discrepancy between an existing situation and a desired state of affairs*. I will speak in favor of this definition because it does not limit creative problem solving to tasks that represent an obvious "gap." As such, the definition also includes problems that represent visions of continuous learning exemplified by the concepts of *creative tension* and *personal mastery* (Senge, 1990).[60]

Problem situations can be distinguished in terms of how much of the problem is clearly given at the start, how much the method for reaching a solution is already at hand, and how extensive the agreement is as to what constitutes a good solution (Getzels, 1975). At the most general level two types of problem situations may be distinguished: *Presented* (well-defined) problem situations and *discovered* (ill-defined) problem situations (Getzels, 1975; Kaufmann, 1988; Kay, 1994). Presented problems have a known formulation, a known method of solution, and a known solution, whereas discovered problems do not yet have a known formulation, a known method of solution, or a solution. The presented (well-defined) problem situation requires problem solving because there is a recognized solution and a specific method of obtaining that solution (Ref. Amabile's (1988) definition of an algorithmic task). In contrast, the *discovered* (ill-defined) problem situation implies the necessity of both problem finding and problem solving (Getzels, 1975), where problem finding involves the formulation of a problem prior to the actions taken to solve the problem (Kay, 1994). Between these extreme cases it is possible to distinguish systematically a number of problem situations that vary in terms of what is known and unknown, and to whom, and hence the degree of problem finding/solving required (ibid.).

As discussed in Chapter 3.5.5, an open-ended problem is a task that has no readily identifiable path to solution, and that may or may not have a clearly defined goal (Ref. Amabile, 1988). I find that a discovered (ill-defined) problem situation should form an additional criterion of open-ended problems. Most "real-world" problems are ill-defined if

[60] The juxtaposition of vision (what we want) and a clear picture of current reality (where we are at a relative to what we want) generates a "creative tension," i.e. a force to bring them together caused by the natural tendency to seek resolution. The essence of personal mastery is to learn how to generate and sustain creative tension in our lives.

they are defined at all (Kay, 1994), and problem finding skills appear to be the best predictor of real-world creative activities (Kay, 1994; Runco and Sakamoto, 1999). Therefore, I now make a further clarification of ill-structured problems.

Kaufmann (1988) points out the importance of making a distinction between different determinants of ill-structured problems (ISPs): *Novelty*, *complexity*, and *ambiguity*. For instance, one source of difficulty in a jig-saw puzzle may be located in the unfamiliarity of the goal structure that is to be attained (novelty). A quite different ISP-producing condition would be the number of pieces that are to be put together to make up the puzzle (complexity). A third condition of difficulty would arise if the task is indeterminate in the sense that quite different goal structures may be visualized, meaning it is hard to see which is the correct one (ambiguity). These dimensions can be varied systematically and *independently* of each other. Each dimension may call for the use of quite different capacities and strategies on the part of the problem solver. Thus, when operating with an undifferentiated concept of an ISP, important differentiations in the problem solving domain may be lost in the blur. According to Kaufmann (1988), the novelty component of difficulty is of primary importance concerning creativity. Following Kaufmann, I argue that novelty is the decisive condition for ill-structured problems, meaning problem finding requires novel responses.[61] Thus, taking account of my argument that open-ended problems should be defined in terms of a heuristic task that represents an ill-structured problem, I define a creative process as an activity that involves both novel problem finding and novel problem solving. At the same time, I find it important to make some points of clarification.

First, I speak in favor of avoiding the terms “ill-structured”, “discovered”, and “finding” because these labels carry a positivist charge assuming that a pre-existing structure can be found or discovered.[62] I choose to substitute “ill-structured” with “open-ended” and “problem finding” with “problem definition” to highlight my constructivist position. As such, *I define “open-ended problems” as heuristic tasks that require problem definition*. Second, even though researchers apparently regard problem definition as an integral part of creative problem solving, I find it important to explicitly call attention to this activity. Ergo, when referring to creative activity, I think of both creative definition and creative solving of open-ended problems. Third, although problem definition is considered the initial task of all problem-solving situations (Kay, 1994), I regard these activities as

[61] Still, I assume that a problem may be difficult due to complexity and ambiguity.
[62] Similarly, I speak in favour of avoiding the terms ”well-structured” and ”presented” problems. Rather, I will refer to such problems as algorithmic problems (Ref. the previous discussion of algorithmic and heuristic tasks in Chapter 3.5.5).

closely interrelated. Therefore, I argue that creative activity is a dynamic process characterized by recurrent cycles of problem definition, problem solving, and problem reconstruction (or *reframing*, ref. Bolman and Deal,1988).

The latter statement suggests that creative activity may also be defined as *improvisation*.

"Improvisation" is rooted in the word "proviso" that means to make a stipulation beforehand, to provide for something in advance, or to do something that is planned for (Barrett, 1998). "Improviso", the opposite of "proviso", thus implies that improvisation deals with the unforeseen and works without a prior stipulation. Accordingly, improvisation is about "taking a leap of faith" while simultaneously being expected to create something novel and coherent. The process involves exploring, continual experimentation, and tinkering with possibilities without knowing where one's queries will lead or how action will unfold. As a result, excitement and risk of failure of is inherent in improvisation (ibid.).

My view of creativity as improvisation opposes the traditional understanding of creativity as a matter of creative thinking and cognitive processes only. It points out that creative activity consists of creative thinking as well as creative action. In this connection, I also argue that action is a prerequisite for creative problem definition and solving. As Weick (1998, p.550) holds: "When faced with incomprehensible events, there is often no substitute for acting your way into an eventual understanding of them." Similarly, Johnstone (1979, p. 95) points out that "good improvisers develop action". Indeed, I suppose that cognitive psychologists implicitly assume that creativity involves action. For instance, Torrance (1962) states that creativity includes adventurous thinking, but also things such as invention, experimentation, exploration, and the like. Nevertheless, my point is that the cognitive approach has led to an over-emphasis on creative thinking to the neglect of creative action. Therefore, I speak in favor of considering creative activity as a dynamic interplay of creative thinking and creative action.

So far, I have reviewed definitions of creativity in light of the four "Ps" of creativity – *Product*, *Press*, *Product*, and *Process* – (Ref. Rhodes, 1961). These perspectives reflect the underlying understanding of creativity as an individual phenomenon. *I state that creativity should also be regarded as a collective phenomenon*.

Innovation is a collective, open-ended activity in which individuals are part of a larger ensemble of specialists who work together on complex tasks without a pre-scripted plan and without certainty of outcomes. The specialists all depend on each other to define and solve open-ended problems, meaning their ability to play well *together* has a major impact on their overall capability to create and implement novel, appropriate products or processes.

Therefore, to point up that creativity is not only an individual capacity but also a *collective* capacity, I introduce a fifth P of creativity: *Partnership.* This term calls attention to my understanding of innovation as a collaborative endeavor in which single experts take part with others in the activity, i.e. are *partners*. As such, "partnership" naturally refers to a social, collective phenomenon in terms of a relationship in which two or more people work together as partners.[63]

3.7 The Creative Partnership

As just indicated, I challenge the widely held understanding of creativity as merely an individual ability or behavior. For instance, highly-skilled orchestral musicians are a necessary, but not sufficient condition for high-quality performances of a symphony orchestra. This is because the musical result depends on how well the musicians play *together*. The musical and collective interplay is intertwined. When musicians play well together, listening to each other and having a common understanding of the music, the sounding result becomes a good one - and vice versa (Oddane, 1990; 1991).[64] Similarly, creative behavior depends on the accomplishments of single individuals and their collective capacity to create results, as illustrated by the jazz band and jazz improvisation.[65]. The great jazz ensembles consist of talented individuals and a shared vision, but what really matters is that the musicians know how to *play* together (Senge, 1990). The establishment of a "groove," the goal of every jazz performance, presupposes that the musicians manage to create a dynamic interplay within the established beat (Barrett, 1998). It involves more than

[63] *Partner* may be defined as a person who takes part with another or others in some activity (HORNBY, A.S. *Oxford Student's Dictionary of Current English. London*: Oxford University Press, 1981. Similarly, *partnership* may be defined as a relationship in which two or more persons, organizations, or countries work together as partners (COLLINS COBUILD. English Language Dictionary).

[64] Actually, musicians who are well tuned into each other create physical resonance effects because they, literally and simply speaking, are on the same wavelength.

[65] I consider "capacity" as a more appropriate concept than "ability". According to COLLINS COBUILD English Language Dictionary "ability" has the following definitions: 1) Your **ability** to do something is the quality or skill that you have which makes it possible for you to do it....2) Someone's **ability** is their general level of intelligence, or their level of skill in doing a particular thing. Moreover, "capacity" is, among other things, described in the following way: The **capacity** of a person, society, or system is 1) the power or ability that they have to do a particular thing... 2) The ability they have to do a particular thing well or to keep on doing it. Reflecting on these concepts I find that they have similar connotations, meaning they may be used interchangeably. However, making a further comparison of the terms I largely associate "ability" with creative potential because of the references to "intelligence" and "level of skill." In a similar way, I associate "capacity" with the actual power to produce creative products. Therefore, arguing that factual creative production is a prerequisite for creativity (ref. previous discussions) I consider "capacity" as the most proper word. In this way, I also intend to highlight the press dimension by stating that creative potential/ability is a necessary, but not sufficient, condition for creative behavior. In this way, I follow, among others, Vernon (1989, p. 94) who defines creativity as "a person's capacity to produce new or original ideas."

simply playing the correct notes; it means a shared "feel" for the rhythmic thrust. When jazz musicians reach this level of "groovy" coordinated action they sometimes experience the ability to perform beyond their capacity. Likewise, Senge (1990, p.10) claims that "when teams are truly learning, not only are they producing extraordinary results but the individual members are growing more rapidly than could have occurred otherwise". Thus, a sound conceptualization of creativity cannot ignore the collective level.

The ever-increasing attention to team work and network collaboration provides further evidence for the importance of highlighting creativity as a collective achievement. Teams are the fundamental learning unit in modern organizations (Senge, 1990; Nonaka and Takeuchi, 1995; Levin et al., 2003). As such, the core of organizational knowledge creation takes place at the group level where knowledge created by individuals is amplified and crystallized through dialogue, discussion, experience sharing, imitation, and observation (Nonaka and Takeuchi, 1995). Furthermore, systems and network approaches to innovation point out that firms do not normally innovate in isolation, but in collaboration and interdependence with other organizations to gain, develop, and exchange various kinds of knowledge, information, and other resources (Van de Ven, 1999; Saviotti, 1997; Edquist, 1997; Fagerberg, 2005).

To summarize, I argue that collective creative capacity is the essence of collective knowledge creation. Creativity is a social, collective phenomenon reflected in collaborative processes in which a number of specialists interact, co-creating new knowledge through dialogue, negotiation, discussion, and experience sharing (Nonaka and Takeuchi, 1995; Greenwood and Levin, 1998; Korsvold, 2002). The specialists are highly *interdependent*, interacting in a complex web of relationships often reaching beyond disciplinary and organizational borders (Gibbons et al., 1994). Therefore, creativity cannot be considered as an individual phenomenon only.

3.8 Summary Discussion

In this chapter I have investigated the concept of creativity. Based on the foregoing review and discussion I propose the following temporary definition of creativity:

Creativity is the individual and collective capacity to define and solve open-ended problems in a novel, appropriate way. Problem definitions and problem solutions are creative to the extent that members of a relevant group independently agree they are creative.

This definition does not fully reflect my understanding of creativity. It serves as an illustration capturing important criteria and characteristics of creativity only. I argue that creativity must be approached as a multifaceted phenomenon rather than as a single construct to be precisely defined. More specifically, taking account of Isaksen's (1988) idea of viewing the study of creativity as a diamond, I suggest that creativity can be modeled as a five-faceted diamond reflecting the five key components outlined in this chapter, namely *Person*, *Press*, *Product*, *Process*, and *Partnership*. Most likely, this suggestion applies to innovation as well. However, I postpone a further elaboration on this idea to the end of Chapter 4, where I present my understanding of the relationship between innovation and creativity.

Chapter 4 What is the Relationship between Creativity and Innovation?

4.1 Introduction

In Chapters 2 and 3 I explored the concepts of innovation and creativity. Still, the following question remains to be fully answered: What is the relationship between innovation and creativity? As discussed earlier, ”creativity” and ”innovation” may be considered discipline-based synonyms because different disciplines use different terms and emphasize various aspects of what seems to be the same phenomenon (Ref. Grønhaug and Kaufmann, 1988; Wehner et al., 1991). Chapters 2 and 3 provide evidence of similarities between conceptualizations of innovation and creativity. For instance, the terms “creativity” and “innovation” are both associated with the production of novel and appropriate work. At the same time, the foregoing discussions indicate that “innovation” and “creativity” may be regarded as more than mere discipline-based synonyms. My temporary definitions (*activity* versus *capacity*) suggest that innovation and creativity may be conceptualized as different, yet intertwined, phenomena. The finding that the concepts often act in concert in titles of publications supports this suggestion. In turn, this observation also indicates that it may be fruitful to operate with a distinction between the terms.

A proper understanding of innovation and creativity requires a closer study of the relationship between these phenomena. In the following, I investigate this relationship through a review of common ways to distinguish innovation from creativity. Observing that most distinctions reflect the Cartesian dualism, I speak in favor of distinctions that transcend traditional narrow and incomplete dichotomies. I assert that my temporary distinction in terms of activity and capacity appears to be a sound way to differentiate between innovation and creativity. Finally, I propose the following definitions:

Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

Creativity is the individual and collective capacity to define and solve open-ended tasks in a novel, appropriate way.

4.2 Differentiation in Terms of Dichotomies

Researchers often distinguish creativity from innovation by means of dichotomies, as seen in Table 4.2.1.

Creativity	Innovation	References
Process	**Product**	Nonaka and Takeuchi (1995); Robinson and Stern (1997); Leonard and Swap (1999); Lumsden (1999); Darsø (2001)
Individual	**Collective**	Becker and Whisler (1967); Amabile (1988); Rosenfeld and Servo (1990); West and Farr (1990); von Stamm (2003)
Idea generation (Green phase) (Divergent mode)	**Idea implementation (Red phase) (Convergent mode)**	Burnside (1990); Rosenfeld and Servo (1990); Amabile (1988); Von Stamm (2003); Amabile et al. (1996)
Thinking	**Doing**	Becker and Whisler (1967); Amabile (1988); Rosenfeld and Servo (1990); West and Farr (1990); von Stamm (2003) Burnside (1990); Rosenfeld and Servo (1990); Amabile et al. (1996)
Emotional	**Rational**	Zalenick (1988); Darsø (2001)
No intentionality of benefit	**Intentionality of benefit**	West and Farr (1990)
Absolute novelty (Discontinuous change)	**Relative novelty (Continuous change)**	Zalenick (1988); West and Farr (1990);
Vertical thinking	**Horizontal thinking**	Zalenick (1988); Darsø (2001)

Table 4.2.1 Differentiation of Creativity and Innovation in Terms of Dichotomies

4.2.1 The Process/Product Dichotomy

Several researchers differentiate between creativity and innovation in terms of a process/product dichotomy (Nonaka and Takeuchi, 1995; Robinson and Stern, 1997; Lumsden, 1999; Darsø, 2001). For instance, Lumsden (1999) distinguishes the creative *process* from its *outcome*, arguing that innovation is an outcome attaining some level of adoption in the society under consideration. Similarly, Leonard and Swap (1999) define creativity as a process of developing and expressing novel, useful ideas where the end result is an innovation, i.e. the embodiment, combination, and synthesis of knowledge in novel, valued new products, processes or services.

I don't regard the process/product distinction as a fruitful way to distinguish creativity from innovation. First, it conflicts with my understanding of creativity as a multifaceted phenomenon that includes both the process and product facets. Second, a conceptualization of innovation as the *end result* of a process creates an artificial distinction between the activities in an innovation project and the "outcome" of these activities. For instance, jazz improvisation, in which the process and product co-occur, demonstrates that the separation between creativity as process and innovation as result is not particularly useful. Third, in improvisatory processes activities and "outcomes" mutually influence each other. As Weick (1995) holds, there is no result *of* process, only a moment *in* process.

4.2.2 The Individual/Collective Dichotomy

Another creativity/innovation dichotomy is the distinction between individual creativity and organizational innovation (e.g. Becker and Whisler, 1967; Amabile, 1988; Rosenfeld and Servo, 1990; von Stamm, 2003). For example, Amabile (1988) argues that *creativity* occurs in the mind and activity of a single person, or, at most, within the minds and activities of a small number of people working together on the same specific problem. In contrast, *innovation* occurs at the level of a *system*. It involves a large number of individuals working together in different units on different aspects of the very general problem of implementing new ideas. Accordingly, the term ”innovation”, when applied to organizations, implies more than simple creative thinking in a single individual; it suggests a ”concerted effort by an aggregate of individuals directed towards doing something novel and appropriate in their business”(Amabile, 1988, p. 146). Similarly, West and Farr (1990) claim that innovation is a social process with the elements of the process being events that occur between people, whereas creativity is an individual cognitive process in which events occur within the person. Likewise, Becker and Whisler (1967) argue that invention is fundamentally a creative act of the individual, whereas innovation is fundamentally a co-operative group action.

I strongly oppose the idea of linking “creativity” and “innovation” to the individual and collective levels, respectively. It reflects the erroneous assumption that creativity is merely an individual phenomenon, fully ignoring that creativity is also a social, collective phenomenon (Ref. Chapters 3.6 and 3.7). In innovation projects the participants are highly interdependent on each other to define and solve open-ended problems. As such, their joint capacity to create and implement novel, appropriate products and processes relates to both the participants’ individual capabilities *as well as* to their capacity to play well together. Therefore, creativity should be perceived as *both* an individual and collective capacity, meaning the individual/collective dichotomy is simplistic and misleading.

4.2.3 The Idea Generation/Idea Implementation Dichotomy

A third way of separating creativity and innovation is proposed by researchers who distinguish the process of *idea generation* from *idea implementation* (e.g. Amabile, 1988; Burnside, 1990; Rosenfeld and Servo, 1990; von Stamm, 2003; Amabile et al., 1996). For instance, Burnside (1990) defines *creativity* as the generation of novel, useful associations (new ideas) and *innovation* as the implementation of creative ideas. Likewise, Rosenfeld and Cervo (1990, p. 252) claim that ”creativity refers to the generation of novel ideas - innovation to make money with them.”

I find that the idea generation/idea implementation dichotomy conflicts with my understanding of creativity and innovation. As discussed earlier, I claim that creativity involves more than mere idea generation (Ref. Chapter 3). In addition, I argue that innovation is not about implementation only. Innovation is a complex activity that comprises *both* creation and implementation of new, appropriate products or processes (Ref. Chapter 2.2). The shortcomings of the creation/implementation dichotomy may be further illustrated through the problem solving model provided by Kolb et al. (1986). According to this model, the essence of problem solving is the dynamic interplay of *green* idea generation phases and *red* idea selection phases.[66] Therefore, borrowing the terms of the current approach, problem solving may be seen as the alternation between *creativity* and *innovation*. From my point of view, ”creativity” and ”innovation” are not appropriate labels of alternating problem solving phases. First, I do not consider creativity and innovation as opposites. Second, I claim that creativity includes the capacity to successfully alternate between green and red phases throughout an innovation process. This is because successful definition and solving of open-ended problems presuppose that team members are tuned into the same phase at all times, i.e. are continuously *aligned* (Senge, 1990; Robinson and Stern, 1997). Accordingly, I regard the understanding of creativity as mere idea generation to be incomplete. Similarly, I claim that the innovation process includes both “green” and “red” phases, meaning that a conceptualization of innovation as mere implementation is inadequate. In addition, the idea is closely related to other problematic assumptions about creativity and innovation, for instance assumptions underlying the linear model of innovation (see Chapter 4.2.7) and the thinking/doing and emotional/rational dichotomies to be presented next. Hence, I conclude that the idea of understanding creativity and innovation as idea generation and idea implementation, respectively, is highly unsatisfactory.

4.2.4 The Thinking/Doing Dichotomy

The individual/organizational and idea generation/idea implementation dichotomies reflect the assumption that creativity involves individual *thinking*, whereas innovation deals with collective *action*. I oppose this distinction because it is based on the Cartesian split emphasizing that true knowledge (or creative products) can be obtained only by the mind, not the body (Nonaka and Takeuchi, 1995). In fact, the body/mind dichotomy is one reason why innovation often fails; it has created a *knowing-doing gap* preventing smart managers from turning appropriate knowledge into action (Pfeffer and Sutton, 2000). Thus, the Western emphasis on explicit knowledge ignores that organizational knowledge creation is based on the *interaction* of explicit and tacit knowledge (Nonaka and Takeuchi, 1995). Claiming that creativity involves both creative thinking and creative doing (Ref. Chapter 3), I thus argue that creativity includes the capacity to overcome the knowing-doing gap, or

[66] As discussed in Chapter 2.2, implementation includes idea selection. Moreover, the green and red phases are characterized by a divergent and convergent “mode,” respectively, i.e. the process of searching, exploring, expanding, developing, and unfolding (divergent)- as opposed to the process of narrowing down and focusing (convergent) (Darsø, 2001).

what may be called the “creativity-innovation” gap in light of the current dichotomy. Similarly, I state that innovation is a social knowledge creation process driven by the dynamic interaction of tacit and explicit knowledge, i.e. learning by thinking as well as by doing. Accordingly, I conclude that the thinking/doing dichotomy of creativity and innovation does not represent a fruitful way of distinguishing between these phenomena.

4.2.5 The Emotional/Rational Dichotomy

According to Darsø (2001), the main difference between creativity and innovation lies in the quality, strength, and active use of *emotions*. In creative sessions emotions are at play. The persons involved express their emotions, e.g. they laugh a lot. This is because creativity allows people to become playful and foolish. In contrast, innovative processes are conceptual and cognitive processes of forming and framing the problem. The topic is investigated rationally and emotions are mostly ignored. Similarly, Zaleznick (1988) points out that innovation involves lower levels of emotion and less anxiety than creativity.

I do not believe emotions represent a sound criterion for separating creativity from innovation. First of all, I reject the apparent assumption that creativity is associated with joyful sessions only. I assume that creativity involves all kinds of emotions ranging from anxiety, frustration, and impatience to passion and happiness. More importantly, though, I do not believe emotions can be separated from rational thinking; thinking guides our emotions and vice versa. As a consequence, people involved in ”innovation projects” or ”creative sessions” are neither entirely emotional nor entirely rational. Accordingly, I oppose the emotional/rational dichotomy of creativity and innovation.

4.2.6 Some Other Dichotomies

According to West and Farr (1990), *intentionality of benefit* most sharply distinguishes innovation from creativity. Innovation has a clear social and applied component, whereas creativity is not supposed to be beneficial. This statement conflicts with my claim that appropriateness is a major criterion of both creative products and innovations (as products). Moreover, West and Farr (1990) also suggest that creativity appears to be understood more as *absolute novelty* than the *relative novelty* of innovation. Zaleznick (1988) supports this idea, linking creativity and innovation to *discontinuity* and *continuity,* respectively. Nevertheless, this approach contradicts my emphasis on relative novelty (Ref. Chapters 2.2

and 3). Furthermore, some researchers distinguish creativity and innovation in terms of opposing thinking processes. For instance, Zaleznick (1988) argues that *creativity* is characterized by *vertical* movements in thought processes, i.e. movements from highly structured and disciplined sequential, logic *secondary process thinking*, to loose, associative and symbolic *primary process thinking* characteristic of the unconscious. In contrast, *innovation* involves *horizontal* modes of thinking. These modes use analogies and past experience, and they depend on a limited number of thinking styles, such as linear reasoning and successive trials. Thus, according to Zaleznick, creativity involves both primary and secondary thought processes, whereas innovation includes secondary thought processes only. Similarly, Darsø (2001) claims that "scientific search" is characterized by secondary thought processes. However, as opposed to Zaleznick, she suggests that creativity is based on primary process thinking only. As such, Darsø separates creativity from "scientific search" by means of the primary- secondary process thinking dichotomy.

Taking account of Darsø's notion that primary and secondary thought processes usually are not sharply separated in normal individuals, I argue that the proposed dichotomies do not represent appropriate differentiation criteria. I also oppose a strong attention to thinking processes, because it reflects the traditional emphasis on creativity as a thinking process only. For these reasons, I reject the idea of separating creativity and innovation in terms of different thinking processes.

Leaving the "dichotomous" approach I now call attention to perspectives viewing creativity as an integral part of innovation, in particular approaches that consider creativity as the point of departure of innovation.

4.2.7 Innovation Equals Creativity Plus Implementation/ Commercialization

Often, creativity is regarded as part of the innovation process. For instance, von Stamm (2003) defines innovation as creativity (idea generation) plus (successful) implementation. Similarly, the head of DnB Nor Innovation states that innovation is about "balancing creativity and commercialization – two almost opposite exercices."[67] These approaches are partly in line with my understanding of creativity and innovation. I consider implementation (and commercialization) as an essential part of the innovation process, and I believe that creativity is closely linked to innovation. Yet, I find that the statements just

[67] Camilla A C Tepfers, Dagens Næringsliv, 2004–05-15-17

referred to reflect problematic assumptions. First of all, they portray creativity and implementation/commercialization as opposites. Pushing the matter to extremes, I do not believe implementation/commercialisation equals innovation *minus* creativity. Rather, creativity is a prerequisite for implementation and commercialization. These activities are at least as challenging as the work aimed at creating new products (Ref. Haanæs, 1999). I propose the hypothesis that the conceptualization of implementation as a non-creative process may be one reason why implementation/commercialization efforts often fail. Likely, business managers who perceive implementation/commercialization as a creativity-demanding activity will succeed more often than managers who consider it as ”plain work” only. Ergo, I speak in favor of viewing creativity as a prerequisite for both the creation and implementation of new, appropriate products or processes.

Furthermore, the view of innovation as creativity plus implementation reflects another problematic assumption, namely the understanding of creativity as the point of departure of innovation processes only. According to Rosenfeld and Servo (1990), creativity is the starting point for any innovation, whereas innovation is the hard work that follows idea conceptions. Holt (1988) claims that creativity is of particular importance during the initial phase of innovation, i.e. idea generation, and von Stamm (2003) perceives creativity as the point of departure of innovation. Similarly, Steinecke (2000), an innovation consultant, argues that creativity creates something new, which in turn initiates the innovation process. Indeed, Holt (1988), Steinecke (2000), and von Stamm (2003) all point out that creativity is needed in all phases of an innovation process. For example, Steinecke claims that creativity and innovation most often cannot be separated because innovation comprises a continuous fill-up of creativity. Still, I find that the writers just referred to implicitly regard innovation as a linear process in which creativity *primarily* is linked to the initial phase – either representing the first phase itself, or having its greatest impact during this stage. As such, their perspectives reflect erroneous assumptions underlying the extremely simplistic linear model of innovation (Ref. Rosenberg, 1991). Certainly, creativity is important in the initial phase of innovation processes. Nevertheless, advocating the perspective that innovation is a complex open-ended activity, I argue that it is naïve to consider creativity merely as the starting point of innovation. Creativity is needed not just in the beginning, but throughout *the entire* innovation process. Creativity is a prerequisite for both definition and solving of open-ended problems and for the creation and implementation of new, appropriate products and processes. Hence, I object to conceptualizations perceiving innovation as a linear process progressing from creativity to apparently non-creative ”hard work”.

Thus, summing up, I oppose the idea of restricting creativity to a particular task (i.e. idea generation) or stage of the innovation process. I speak in favor of distinctions that do not consider creativity and implementation/commercialization as opposites or draw attention to linear conceptualizations of innovation.

4.2.8 Summary Discussion - Proposal of the Activity/Capacity Distinction

Through the foregoing discussions I have criticized common ways to distinguish creativity from innovation, claiming that they represent incomplete and narrow views of both creativity and innovation. The distinctions reflect the Cartesian dualism and thus a tendency to view the world in terms of either-or approaches. For this reason, I argue that attempts to differentiate between creativity and innovation should cut across this intellectual tradition and move *beyond* dichotomies: Creativity and innovation are not matters of products *or* processes, individuals *or* groups, creation *or* implementation, emotions *or* rational thinking, or thinking *or* doing. What appear to be opposite ends of a dichotomy are *complementary* entities, interacting with each other to create something new (Nonaka and Takeuchi, 1995). It is the dynamic and simultaneous interaction between creation and implementation, thinking and doing, emotions and rationality, individuals and groups, etc. that creates something new and different. As Nonaka and Takeuchi (1995, p.236) put it:

> *…In other words, A and B create C, which synthesizes the best of A and B. C is separate and independent of A and B, not something "in-between" or "in the middle of" A and B…*

I argue that my temporary definitions of innovation and creativity represent a reasonable and innovative alternative to the faulty traditional dichotomies. The suggestions that innovation includes creation *as well as* implementation of new, appropriate products/processes and that creativity deals with *both* problem definition *and* problem solving emphasize the dynamic interplay and complementarity of apparent opposites. In a similar way, my argument that creativity and innovation should be conceptualized as multifaceted phenomena overcomes the shortcomings of the dichotomies proposing a separation in terms of facets such as the individual-collective (*person-partnership)* and process-product dichotomies. Moreover, my temporary definition of innovation and creativity as an *activity* and a *capacity*, respectively, stands for a fruitful way to distinguish between these multifaceted phenomena. First, this distinction points out that creativity and innovation may be perceived as closely related phenomena: The individual and collective capacity to define and solve open-ended problems in a novel, appropriate way (creativity) is a prerequisite for the creation and implementation of new, appropriate products in order to create significant economic benefit and other values (innovation). This statement, in turn, points out that the involvement of open-ended problems is the salient characteristic linking creativity and innovation. Second, the conceptualization of creativity as the capacity to define and solve open-ended problems does not restrict creativity to a particular task or stage in the innovation process. As such, this definition is consistent with my argument that creativity is needed throughout the entire innovation process and that creativity is a prerequisite for both the "creation" and "implementation" activities. Third, the understanding of creativity as both an individual and a collective capacity cuts across the limitations of the individual-organizational dichotomy outlined in Chapter 4.2.2. Therefore, I conclude that an understanding of creativity as a capacity and innovation as an activity represents a useful way to distinguish creativity from innovation.[68] Hence, based on the foregoing discussion I propose the following definitions of the two interrelated phenomena:

Innovation is collective, open-ended activity aimed at the creation and implementation of new, appropriate products or processes in order to generate significant economic benefit and other values.

Creativity is the individual and collective capacity to define and solve open-ended problems in a novel, appropriate way.

However, I emphasize that these definitions first and foremost serve as illustrations capturing important criteria and characteristics of innovation and creativity only. Innovation and creativity must be conceptualized as multifaceted phenomena rather than as single constructs to be precisely defined. More specifically, I argue in favor of conceptualizing creativity and innovation as multifaceted phenomena composed of the *Person*, *Press*, *Product*, *Process*, and *Partnership* facets. This argument forms the basis for the 5P diamond of innovation and creativity and the literature review presented in the next chapter.

[68] This distinction is similar to Nystrøm's (1979) distinction between innovation as radical, discontinuous change and creativity as the ability to devise and successfully implement such changes.

Chapter 5 Five Facets of Innovation and Creativity: Person, Press, Product, Process, and Partnership

5.1 Introduction

The purpose of this chapter is to shed further light on the five facets or Ps of innovation and creativity introduced in Chapters 3 and 4, i.e. *Person*, *Press*, *Product*, *Process*, and *Partnership*. I introduce my 5P diamond model that forms the basis for the analysis and discussion of my empirical data and make a brief review of literature that elaborates on the five Ps in question.

In Chapter 5.2 I present my 5P diamond model of innovation and creativity, arguing that it represents a powerful conceptual framework for studying innovation as a multifaceted phenomenon. Then, in Chapters 5.3 through 5.7 I sequentially call attention to each individual P, reviewing theories and perspectives providing better insight into the five facets of innovation and creativity. Chapter 5.2 presents the *Person* facet, highlighting individual characteristics, knowledge, and skills promoting innovation. Chapter 5.3 sheds light on the *Press* facet, providing an overview of work-environmental factors supporting creativity. In Chapter 5.4 the *Product* facet is in focus. This chapter discusses characteristics of creative/innovative products, recalling main points discussed in Chapters 2 and 3. Chapter 5.5 deals with the *Process* facet, shedding light on characteristics of innovation as a process. Finally, Chapter 5.6 portrays the *Partnership* facet, calling attention to characteristics of innovation as a social, collective achievement. The individual "P"- chapters conclude with a list of facet-specific research questions aimed at providing a sound basis for answering the thesis' main research question.

5.2 Presentation of the 5P Diamond Model of Innovation and Creativity

The foregoing chapters led up to the main argument that innovation must be conceptualized as a multifaceted phenomenon. This argument clearly points to the need for a broad approach to the study of innovation. More specifically, it implies a *multiperspective* approach in terms of making use of perspectives and theories from several disciplines to overcome the limitations of the traditional single-discipline approaches that have made innovation research an unproductively fractionated endeavour (Ref. Chapter 1). Inspired by the multiperspective thinking advocated by Bolman and Deal (1987; 1991) and Morgan (1988; 1997), I thus aim to study innovation in a way that integrates insight from perspectives that previously have been studied from separate points of view.

In Chapters 3 and 4 I implicitly introduced a model for studying innovation as a multifaceted phenomenon composed of five facets that (for the most part) have been studied independently. I now explicitly present this conceptual framework and argue that it represents a powerful analytic tool for obtaining a comprehensive understanding of innovation.

Through the conceptual study of creativity (Ref. Chapter 3) I got acquainted with two contributions, Isaksen (1988) and Rhodes (1961), which provided specific ideas of how to create a broad model for the analysis and discussion of my empirical data. Isaksen's (1988) suggestion of viewing the study of creativity as a diamond directed my attention to a diamond model. The image of a jewel with several facets elegantly and intuitively captured my emphasis of viewing innovation as a complex phenomenon composed of multiple inseparable parts. For this reason, I went for a diamond model.

In turn, this decision raised the question of *facets*: Which facets should the diamond consist of? Here Rhodes' (1961) finding that definitions of creativity may be grouped into four strands, *the four Ps of creativity*, proved to be useful.[69] The four strands Rhodes discussed included information about the personality, intellect, traits, attitudes, values, and behavior (PERSON); the stages of thinking people go through when overcoming an obstacle or achieving an outcome that is both novel and useful (PROCESS); the relationship between people and their environment, the situation conducive to creativity

[69] Rhodes used the image of a prism to describe his findings. He reported: When analyzed, as through a prism, the content of the definitions form four strands. Each strand has unique identity academically, but only in unity do the four strands operate functionally (Rhodes, 1961, p. 307). However, he did not present a four-faceted diamond model of creativity. Accordingly, my diamond model is not an extended version of an existing diamond model, but a new construct in terms of a novel combination of existing material.

(PRESS); and the characteristics of artifacts of new thoughts and ideas, inventions, designs, or systems (PRODUCT). I noticed Rhodes' (1961) observation that the strands are not mutually exclusive, but overlap and intertwine, and that each of the four strands operate as identifiers of some key components of the larger, more complex concept of creativity (Isaksen, 1988). As such, the four Ps of creativity appeared as the very candidates for the facets in my diamond model.

At the same time, I found that the four Ps of creativity alone did not constitute a satisfactory ensemble of facets because they reflected the underlying assumption of creativity as an individual phenomenon. Arguing that a broad approach to innovation cannot ignore the collective dimension of creativity I hence introduced a fifth P, *Partnership*, to explicitly highlight creativity as a social, collective achievement. Accordingly, I model innovation as a diamond composed of five facets: *Person*, *Press*, *Product*, *Process* and *Partnership*. I call the model *the 5P diamond model of innovation and creativity*. The phrase "model of innovation and creativity" underlines my argument that a broad approach to innovation must include attention to creativity (Ref. Part I: Conceptualizing Innovation and Creativity). I define the facets of innovation and creativity as follows: The *Person* facet highlights individual characteristics, knowledge and skills promoting innovation. The *Product* facet deals with characteristics of innovations (products). The *Press* facet sheds light on conditions conducive to creativity, e.g. work-environmental factors. The *Process* facet brings characteristics of the innovation process into focus. Finally, the *Partnership* facet calls attention to characteristics of innovation as a social, collective achievement. I argue that the 5P diamond model represents an innovative analytic tool in the field of innovation, enabling the integration of insights derived from facets previously studied from separate points of view.

The 5P diamond model of innovation and creativity is shown in Figure 5.2.1 below. It illustrates my conceptualization of innovation as a multifaceted phenomenon.[70] The diamond represents a complex phenomenon composed of five facets, each representing *one* of a multitude of parts that form it into a whole. Each facet illuminates a different part of the diamond.

[70] Strictly speaking, the facets of a diamond are the flat surfaces that have been cut on its outside. However, in my 5P diamond model the facets are visualized as boxes at the vertices of the diamond.

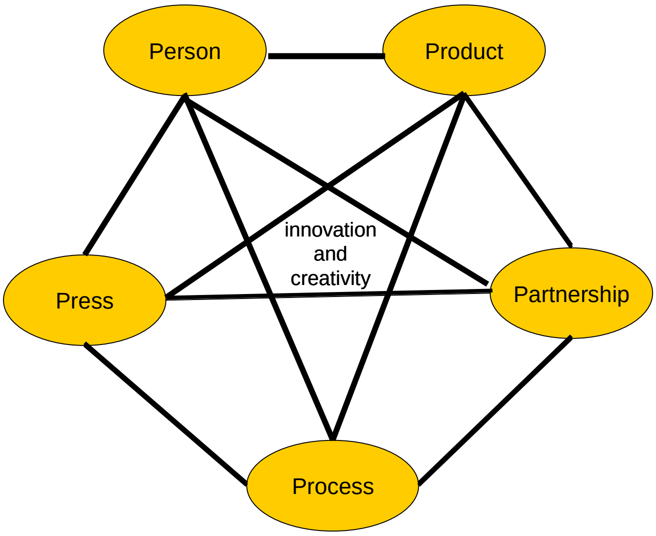

Figure 5.2.1 The 5 P Diamond Model of Innovation and Creativity

The 5P diamond model visually reminds us that when our attention is directed at only one of the facets, care must be taken to avoid the tendency to overlooking the whole while concentrating on a single part. Each facet provides distinctive, yet *partial* knowledge of innovation. To get a comprehensive understanding of innovation, all facets must be taken into consideration. By sequentially directing our attention to each separate facet, i.e. *reframing* (Bolman and Deal, 1987), we gradually obtain a richer and broader understanding of the depth and complexity of innovation. Still, it is unrealistic and naïve to believe that this approach will produce a perfect or complete understanding. No ensemble of facets will ever capture the full complexity of innovation. The point is that the study of several facets enables a much deeper understanding of the complexity of innovation than the partial insight provided by each facet alone. Accordingly, I argue that my 5P diamond of model of innovation and creativity represents a powerful conceptual framework for obtaining a comprehensive understanding of innovation as a multifaceted phenomenon.

5.3 The Person Facet of Creativity and Innovation

5.3.1 Introduction

In this chapter I call attention to individual characteristics, knowledge, and skills promoting innovation efforts by reviewing works from the fields of "creativity" and "innovation" research respectively. To portray "creative" individuals I give a brief outline of individual trait approaches followed by a review of two partly complementary, partly overlapping componential models of creativity. These models, which are proposed by Amabile (1983a/b; 1988; 1996) and Csikszentmihalyi (1999; 2001) respectively, point up that individual creativity does not depend on personal characteristics only, but also on the context in which individuals operate. Finally, I highlight the "entrepreneur", "entrepreneur" and some other key figures appearing in contributions within the field of innovation.

5.3.2 Characteristics of Creative Persons

Some of the traits frequently held to be associated with creative achievement are a desire for autonomy and social independence or lack of concern for social norms,[71] high tolerance of ambiguity, a propensity for risk taking, and anxiety - though probably only at moderate rather than high levels (King, 1990). Likewise, creative persons have a high degree of self-discipline in matters concerning work, an ability to delay gratification, and perseverance in the face of frustration (Amabile, 1983a). The most salient characteristic of creative individuals, though, is a constant curiosity – an ever renewed interest in whatever happens around them (Csikszentmihalyi, 1999). This enthusiasm for experience is often seen as part of the ”childishness” attributed to creative people. The creative person (artist or scientist) in general is also distinguished by relatively high numbers of asocial characteristics and traits that revolve around the need for power and diversity. These are: introversion, social independence, hostility, arrogance, drive, ambition, self-confidence, openness to experience, flexibility of thought, and an active imagination (Feist, 1999).

Individual trait approaches provide knowledge of particular clusters of personality traits that are found fairly consistently among individuals exhibiting high levels of creativity. Still, they represent a naïve and incomplete view of individual creativity. The individual trait approaches implicitly assume that creative persons are born with characteristics that

[71] Highly creative people are often labeled ”oddballs” by superiors (King, 1990).

differentiate them from non-creative persons.[72] As such, they fully ignore the impact of learning and the social environment, and thus circumstances conducive to creativity.[73] Clearly, no individuals operate in a vacuum, meaning creative performance does not solely rely on “genetic” factors. A proper understanding of individual creativity thus necessitates attention to more system-oriented approaches that model individual creativity as the confluence of both personal and contextual factors. For this reason, I now call attention to the componential/systems models proposed by Amabile (1983a/b; 1988; 1996) and Csikszentmihalyi (1999; 2001). These models conceptualize individual creativity as the confluence of personality, cognitive, motivational, and social-cultural variables.

5.3.3 Systems Models of Individual Creativity

Amabile (1983a/b; 1988; 1996) defines creativity as the production of ideas that are reliably assessed as creative by appropriate judges (Ref. Chapter 3). Her componential framework of creativity includes three main components (see Figure 5.3.1): *domain-relevant skills*, *creativity- relevant skills*, and *task motivation*. *Domain-relevant skills* are the basis for performance in any domain, representing the set of cognitive pathways for solving a given problem or doing a task. They depend upon innate cognitive, perceptual, and motor abilities, as well as formal and informal education in the domain of endeavor. This component comprises familiarity with and *factual* knowledge of the domain in question, facts, principles, opinions about various issues in the domain, knowledge of paradigms, performance ”scripts” for problem solving, and aesthetic criteria. It also includes technical skills that may be required by a given domain, i.e. laboratory techniques or studio art techniques, and special domain-relevant ”talents” that may contribute to creative productivity.[74]

[72] Ref. Chapter 3.3.3 Creativity – an Ability of the Gifted Few or Most People?
[73] As such, the study of characteristics associated with creativity cannot by itself tell us how creative performance in work settings in general can be stimulated or blocked other than by selective hiring or firing (King, 1990).
[74] According to Amabile (1983a), talent in the present context refers to a special skill for which an individual appears to have a natural aptitude. She points out mental imagery as a good example of a talent, noticing that although most individuals assert that they experience some type of mental imagery, some outstanding creative people appear to have an extraordinary talent for calling up visual, auditory, or even kinesthetic images. For this reason, she finds it reasonable to suggest that different types of vivid imagery are important domain-relevant skills for creativity in several different fields and to consider outstanding levels of this skill as ”talent”.

Domain- relevant skills	**Creativity-relevant skills**	**Task motivation**
Includes: Knowledge about the domain Technical skills required Special domain-relevant skills	Includes: Appropriate cognitive style Implicit or explicit knowledge of heuristics for generating novel ideas Conducive work style	Includes: Attitudes toward the task Perceptions of own task motivation for undertaking the task
Depends on: Innate cognitive abilities Innate perceptual and motor skills Formal and informal education	Depends on: Training Experience Personality characteristics	Depends on: Initial level of intrinsic motivation toward the task Presence or absence of salient extrinsic constraints in the social environment Individual ability to cognitively minimize extrinsic constraints

Figure 5.3.1 The Componential Framework of Creativity (Amabile, 1983a).

By emphasizing the importance of domain-relevant skills, Amabile objects the argument that too much expertise in a field may inhibit creativity (Robinson and Stern, 1997, p.45-47). According to her, an increase in domain-relevant skills can only lead to an increase in creativity; "*while it is possible to have "too many algorithms", it is not possible to have too much knowledge*" (Amabile, 1983a, p.71).

Creativity-relevant skills represent the "something" extra in creative performance. An individual's use of creativity-relevant skills determines the extent to which his product will surpass previous products in the domain. This component covers three types of skills of which some depend on personality characteristics, whereas others depend on training and experience. The first type is a cognitive style characterized by a facility in understanding complexities and the ability to break set during problem solving.[75] Next, knowledge of *heuristics* is familiarity with general rules that can be of aid in approaching problems or generating novel ideas. Heuristics such as "*When all else fails, try something counterintuitive*" or "*Make the familiar strange*" are examples here. The third type of creativity-relevant skills is a work style conducive to creative production. For instance, the ideal work style includes the ability to concentrate effort of attention for long periods of time and the ability to do "productive" forgetting.

[75] For instance, *divergent thinking* (Ref. Guildford, 1950) characterized by fluency, flexibility, and originality of mental operations, and *discovery orientation*, i.e. the tendency to find and formulate problems where others have not seen any, are extensively studied attributes of the creative cognitive style (Csikszentmihalyi, 1999).

Nevertheless, no amount of domain- or creativity-relevant skills can compensate for a lack of appropriate motivation to do an activity. Therefore, *task motivation* is the most important component of creativity. To some extent, a high degree of proper motivation can make up for a deficiency of the other skills. Task motivation includes the individual's baseline attitude toward the task and the individual's perceptions of his or her reasons for undertaking the task in a given instance. This attitude depends on the person's intrinsic motivation, on external social and environmental factors, and on a person's ability to cognitively minimize the salience of controlling extrinsic constraints. [76] Since task motivation depends strongly on the work environment, this is an easy component to address in attempts to stimulate creativity. According to the *intrinsic motivation principle*, intrinsic motivation is conducive to creativity, and controlling extrinsic motivation is detrimental to creativity. Informational or enabling extrinsic motivation (e.g. enabling rewards or performance feedback), however, can be conducive, particularly if initial levels of motivation are high (Collins and Amabile, 1999).[77] Amabile's componential framework suggests that people are most likely to be most creative within their *creative intersection*, that is, where the individual's domain-relevant skills overlap with the individual's strongest interests and creative-thinking skills (Collins and Amabile, 1999).

According to Csikszentmihalyi (1999; 2001), creativity occurs when a person makes a change in a domain. His main point is that creativity is not merely an individual process. Creativity is a socio-cultural phenomenon constructed through the *interaction* between an individual and a social system making judgments about the individual's contribution. For this reason, creativity cannot be separated from persuasion.

Csikszentmihalyi's systems model consists of three elements: *Culture* consisting of interrelated *domains*; *society* covering all *fields* operating within a time-space framework;

[76] *Intrinsic motivation* is defined as the motivation to engage in an activity primarily for its own sake, because the individual perceives the activity as interesting, involving, satisfying, or personally challenging; it is marked by a focus on the challenge and the enjoyment of the work itself. Thus, the major components of intrinsic motivation are self-determination, competence, task involvement, curiosity, enjoyment, and interest (Collins and Amabile, 1999). By contrast, *extrinsic motivation* is defined as the motivation to engage in an activity primarily in order to meet some goal external to the work itself, such as attaining an expected reward, winning a competition, or meeting some requirement. It is marked by a focus on external reward, external recognition, and external direction of one's work (ibid.). It follows that expected reward, expected evaluation, surveillance, time limits, and competition are five sure "fire-killers" of intrinsic creativity (Nijstad et al., 2003).

[77] *The intrinsic motivation principle* represents a revision of the prevailing *intrinsic motivation hypothesis* (Ref. Amabile, 1983a, p. 91), that is, the view that intrinsic and extrinsic motivations are inversely related (Collins and Amabile, 1999). This is because Amabile later identified two types of extrinsic motivators: *Synergistic extrinsic motivators* that increase an individual's concentration on the task, that is, provide information or enable the person to better complete the task, and that can act in concert with intrinsic motives, and *nonsynergistic extrinsic motivators* that lead the person to feel controlled and hence are incompatible with intrinsic motives.

and the *individual* (see Figure 5.3.2). The model underscores that creativity can be observed only at the intersection where individuals, domains, and fields interact.

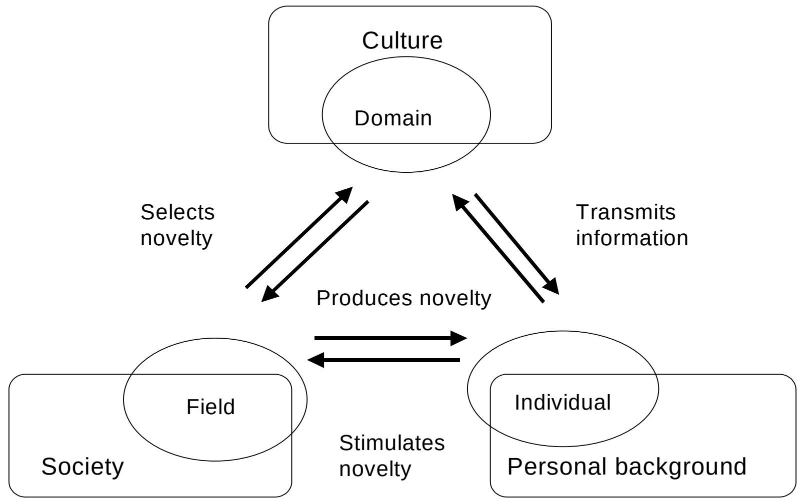

Figure 5.3.2 The Systems View of Creativity (Csikszentmihalyi, 1999; 2001).

For creativity to occur, a set of rules and practices must be transmitted from the domain to the individual. The individual must then produce a novel variation in the content of the domain. In turn, the variation must be selected by the field for inclusion in the domain.

The domain lays the foundation for creativity. The rules, procedures, and opinions embedded in any domain (e.g. music, mathematics, electronic engineering) form the basis for individual performance in the domain and serve as reference for judgments of novelty within it. Since the accessibility of a domain depends on several variables, the individual's acquisition of this knowledge does not only depend on his/her motivation to learn to perform according to its rules, but also on his/her possibility of entering the domain in the first place.[78] As such, the individual capacity to introduce a novel variation in a domain depends on the interaction of individual and cultural factors. Still, individual knowledge of the domain and creativity-boosting personal qualities are not sufficient for creativity to occur. Potential creative products are not adopted unless they are sanctioned by the *field*, that is, the group of gatekeepers (e.g. teachers, critics, journal editors) who practices a given

[78] Csikszentmihalyi (1999) points out a large number of variables explaining how cultures and domains may affect the incidence of creativity. For instance, the way information is stored, the accessibility of information, and how open the culture is to other cultures influence creativity. The more permanent and accurate the storage, and the more clear and accurate the system of notation, the easier it is to assimilate past knowledge and hence to take the next step in innovation. The more accessible the information is, the wider the range of individuals is who can participate in the creative process. The more exposed the culture is to information and knowledge from other cultures the more likely it is that innovation will arise.

domain and decides what belongs to the domain and what does not. Since fields vary in terms of their receptiveness to innovation, creativity does not only depend on individuals' capacity to convince fields about the virtue of the novelty one has produced, but also on the fields' responsiveness to novel ideas.[79]

Thus, Csikszentmihalyi (1999; 2001) emphasizes that creativity cannot be recognized except as it operates within a system of cultural rules, and it cannot bring forth anything new unless it can enlist the support of peers. It follows that the occurrence of creativity is not simply a function of how many would-be creative persons there are, but also of how accessible the various domains are and how responsive the fields are to novel ideas. For this reason, Csikszentmihalyi speaks in favor of devoting attention to communities and their influence on individual creativity instead of focusing exclusively on individuals.

The implications of Csikszentmihalyi's systems perspective parallels Amabile's attention to the influence on work-environmental factors on creativity. However, where Csikszentmihalyi (1999; 2001) primarily highlights how communities influence creativity in terms of accessibility to the domain and responsiveness to novel ideas, Amabile (1983a/b;1988;1996) calls attention to the importance of creating work environments that stimulate task motivation. Also Csikszentmihalyi (1999; 2001) emphasizes the importance of motivation. He argues that intrinsic motivation is a salient characteristic of creative individuals. Still, apart from noticing that motivation plays an important role in individuals' decision to enter into domains, he does not explicitly discuss how communities may or may not nurture individual task motivation. In fact, Csikszentmihalyi seems to regard high levels of intrinsic motivation as a fixed personal quality once an individual has learned the rules and practices of the domain attracting them in the first place.

When it comes to other characteristics of creative persons, the perspectives of Amabile and Csikszentmihalyi converge in terms of the recognition of domain-specific knowledge and creative-thinking skills, and in terms of the insistence on these components depending on innate personality characteristics, the social-cultural background, and formal/informal

[79] According to Csikszentmihalyi (1999), the field may affect the incidence of creativity in many ways. For instance, creativity depends on the questions of whether the field is able to obtain resources from society, whether the field is independent of other societal fields and institutions, how much the domain constrain the judgments of the field, how institutionalized the field is, and how much change the field supports. A field is likely to stagnate if it cannot provide either financial or status rewards to its practitioners. When a field is overly dependent for its judgments on religious, political, or economic considerations, it is unlikely to select the best novel ideas. On the other hand, being completely independent of the rest of society also reduces the field's effectiveness. Furthermore, when the criteria of a domain do not specify which novelty is an improvement, the field has more discretion in determining creativity. It is likely that both too little and too much freedom for the field is inimical to creativity. When it comes to the question of degree of institutionalization, a certain amount of internal organization is needed for a field to exist. Too much energy vested in self-preservation usually results in a field that becomes highly bureaucratic and impervious to change. Finally, criteria that are too liberal for accepting novelty may end up debasing the domain; criteria that are too narrow result in a static domain.

training and experience. At the same time, the perspectives differ with respect to the role of individuals vis-à-vis fields making judgments of the individuals' products.

As is evident from previous discussions, Amabile and Csikszentmihalyi agree that creativity is not a real objective quality, but refers to the acceptance by a particular field of (appropriate) judges.[80] Similarly, both emphasizes that the obtainment of social acceptance requires that novel ideas are made known to the field. Clearly, would-be creative products can never become creative if they remain private secrets known by the inventors only. However, where Amabile (1996) recognizes the importance of communication without further reference to the work aimed at gaining social acceptance, Csikszentmihalyi (1999;2001) argues that the ability to convince the field about the virtue of the novelty one has produced is an important facet of personal creativity. The opportunities one has to get access to the field, the network of contacts, the personality traits that make it possible for one to be taken seriously and the ability to express oneself in such a way as to be understood are all part of the individual traits that make it easier for someone to make a creative contribution. As such, Csikszentmihalyi defines individual interpersonal skills as a component of individual creativity, while Amabile (1996) does not discuss such skills at all. Thus, the perspectives of Amabile and Csikszentmihalyi differ with respect to the role interpersonal skills and task motivation play in their systems models of creativity.

5.3.4 The Entrepreneur and Intrapreneur

Pinchot (1985) describes *intrapreneurs* as those who assume hands-on responsibility for creating innovation of any kind within an organization ("those dreamers who do"). Similarly, an *entrepreneur* is someone who fills the role of an intrapreneur outside the organization.[81] According to Kao (1991), the following list covers essential traits of the entrepreneur:[82] total commitment, determination, and perseverance; drive to achieve and grow; opportunity and goal orientation; initiative and personal responsibility; persistence in problem solving; realism and a sense of humor; emphasis on seeking and using feedback; internal locus of control; calculated risk taking and risk seeking; low need for status and

[80] Amabile's (1996) attention to a consensual definition of creativity is discussed in Chapters 2.2, 2.3 and 4.
[81] As entrepreneurs and intrapreneurs appear to share essential characteristics (Ref. Pinchot, 1985), I here treat the terms as synonyms.
[82] Kao (1991) emphasizes that the trait approach is far from satisfactory. Many traits used could just as easily apply to managers. It also lacks specificity, refers largely to men, and is not applicable in all cultures. It has also been shown that certain characteristics of entrepreneurs, if taken to an extreme, can be a drawback to a successful enterprise in the low run.

power; and integrity and reliability.[83] Another salient characteristic of entrepreneurs is their superior capacity to make judgmental decisions with far-reaching consequences. The entrepreneur has a ”finely tuned antenna” and intuition enabling him or her to see opportunities where others do not (Hébert and Link;1988; Kao,1991; Casson 2003). Similarly, intrapreneurs have a strong visionary power and an ability to visualize and image business and organizational realities in the way customers will respond to innovation. As such, they have a firm grasp of business and market reality.

Furthermore, successful entrepreneurs have an extroverted style enabling the achievement of his or her goals through others (Kao, 1991).[84] For instance, political skills are necessary to gain sponsors who protect ideas, fund projects and provide relevant assistance (Pinchot, 1985). Intrapreneurs also have team-building skills and the ability to involve good people – a challenge that requires creativity. In addition, intrapreneurs are naturally action-oriented with an unstoppable need to turn vision into action. They combine strong conceptual skills with ”dirt-under-the-fingernails” action and don’t have standards about what kinds of work are beneath them. They are strongly dedicated to work, have a need for achievement, are self-determined goal setters, set high internal quality standards, view failure as a learning experience, manage risk, and are loyal to long-term business objectives (ibid.).

5.3.5 Characteristics of Key Persons in Innovation Projects

Empirical research shows that committed top managers and experts positively influence the success of industrial research, product development, and diffusion (Gemünden, 1988). Whereas heroic one-man theories like Schumpeter’s dynamic entrepreneur dominated in the early stage, later contributions have postulated a division of roles (ibid.).[85] Recognizing communication problems between inventors and top managers, Schön (1963) proposes a second man, *the product champion*, who promotes new inventions. He is required to overcome underground resistance to change. He has to be committed to the idea, must have considerable power and prestige in the organization, and needs to know and know *how* to use the company’s informal systems of relationship. In addition, his interests must cut across the special interests (technology, marketing, production, and finance) that are

[83] His list is based on the finding of Timmons et al (1985), *New Venture Creation*. As seen, the list of traits cover many traits recognized as salient characteristics of creative persons (Ref. Chapter 5.3.2)
[84] Accordingly, the persuasive part of creativity is an essential part of entrepreneurship, too.
[85] The selection of Schön (1963), Chakrabarti (1974), and Witte (1977) to be outlined next is inspired by Gemünden’s (1988) article on ”promotors”.

essential to the development of the product or process. Schön gives only anecdotal empirical evidence for his hypothesis, but later research provides further evidence (Gemünden, 1988). For instance, Chakrabarti's (1974) study into the success on 45 NASA innovations showed that the presence of a product champion playing a dominant role in integrating research-engineering interaction was strongly related to success. Chakrabarti indicates that a successful product champion has the following qualities: technical competence, knowledge about the company, knowledge of the market, drive and aggressiveness, and political astuteness.

Witte (1977) calls attention to two other promotors*: Promotors of power* and *promotors of know-how*. A *promotor of power* is a person who actively and intensively promotes an innovation process by means of hierarchic power (top manager), whereas a *promotor of know-how* encourages an innovation process by means of object- specific know-how.[86] In particular, the tandem coalition of these promotors contributes to successful innovations.

The final promotors to be presented here are Philips' (1988) *souls of fire.* The souls of fire are individual key actors deeply involved in work organization development projects who have an important impact on the development and viability of the new organizational solutions. According to Philips (1988), souls of fire's ability and intention to reflect seem to increase their individual capacity for altering and developing the work organization. Similarly, cooperation in a retroactive construction of meaning, that is, participation in conversions carried out during and after the effort, enables him or her to achieve fruitful work organization development. Accordingly, the ideal *soul of fire* has a highly developed practical and reflective/theoretical competence; learns from his/her experience; adopts a boundary role, i.e. a position on the boundary of the company unit which is experiencing change to exercise his influence on the development effort indirectly; creates conditions in which other persons will carry out measures for change and learning; and, finally, facilitates and cooperates in a retroactive construction of meaning. Both the effort and the actor himself benefits from the actor's capacity to arrange and participate in joint reflection and learning (ibid.).

[86] The promotor types correspond to the two barriers faced in innovation processes. The barrier of will arises because innovations alter the status and balance of power, whereas the barrier of capability is explained by the very nature of the innovation, which is not only unknown as a technological object, but also as a source of new demands for its utilization.

5.3.6 Discussion and Formulation of Research Question

Chapters 5.3.2 through 5.3.5 highlighted the *Person* facet of creativity and innovation by shedding light on contributions from the fields of "creativity" and "innovation" research respectively.

When I compare the trait approaches describing "creative" individuals with those highlighting "innovation promotors"[87], I notice that both "camps" call attention to persistence in problem solving, propensity for risk taking, and active imagination (See Table 5.3.1 below).

Creativity research Traits associated with "creative" persons	**Innovation research** Traits associated with "innovation promotors"
persistence in problem solving, propensity for risk taking, active imagination	
asocial	social
introverted	extroverted
low level of interpersonal skills	high level of interpersonal skills
thinkers (carry out mental activity)	doers (carry out practical/social activity)
operating in isolation ("lonely heroes"/"hermits")	operating in a social environment

Table 5.3.1 Individual traits associated with "creative" individuals and "innovation promotors" respectively.

Still, the respective portraits first and foremost represent dichotomies used to separate "creativity" from "innovation".[88] Broadly speaking, *the trait approaches model creative persons as asocial, introverted persons acting in isolation ("the lonely heroes") and "innovation promotors" as social people achieving his or her goals through others*: Where creative persons have a large number of asocial traits, "innovation promotors" are extroverted people characterized by strong interpersonal skills. Where creative persons are distinguished by intrapersonal thinking, curiosity, and mental flexibility, appearing to operate as secluded hermits, "innovation promotors" are recognized by their actions and

[87] I hereafter use "innovation promotors" as a collective term for the key figures appearing in the contributions from the field of innovation research.
[88] Ref. Chapter 4.

social interaction within a larger context. An obvious implication is that creative individuals have low levels of interpersonal skills, whereas the opposite is true for "innovation promotors".

In other words, the portrait of "creative" persons mirrors the assumption that creativity is a mental, intrapersonal capacity (individual phenomenon), while the picture of "innovation promotors" tacitly assume that innovation is a social co-operative group activity (collective phenomenon). These assumptions, in turn, reflect the common definitions of creativity and innovation as the creation and implementation of novel ideas respectively. As such, the respective trait approaches suggest a clear *division of roles* between individuals creating novel, useful contributions and persons promoting the further development and implementation of these. This mistaken idea also underlies Amabile's (1983a;1988;1996) framework.[89] Finally, the image of (introverted) inventors who hand over their creative outcomes to (extroverted) "implementors" inevitably calls attention to the linear model of innovation.

As is evident from Chapters 2 through 4, I strongly oppose the conceptualizations of creativity and innovation reflected in the portraits of "creative" persons and "innovation promotors" presented above. In particular, I reject the idea that creative individuals operate in a vacuum in which interpersonal skills are irrelevant. For this reason, I consider Amabile's ignorance of interpersonal skills as a major weakness of her componential model. For the same reason, I claim that Csikszentmihalyi (1999; 2001) provides a powerful corrective to the erroneous assumption in question. His argument that creativity is constructed through a social *interaction* in which individual interpersonal skills play a significant role is important. Indeed, the opportunities one has to get access to the field, the network of contacts, the personality traits that make it possible for one to be taken seriously and the ability to express oneself in such a way as to be understood, cannot be ignored in models of individual creativity. However, this statement does not mean that creative persons have to do the entire persuasion job alone. That is, the argument that interpersonal skills are a natural part of creativity does not devaluate the idea of a *product champion* acting as a promotor on behalf of an inventor (Ref. Schön, 1963; Chakrabarti,1974). My point is: In order to be creative, an inventor must be able to convince the field by virtue of his/her own skills, by building alliances with relevant others (e.g. *product champions*), or

[89] As discussed in Chapter 4.2.2, Amabile (1988) argues that *creativity* occurs in the mind and activity of a single person, or, at most, within the minds and activities of a small number of people working together on the same specific problem. In contrast, *innovation* occurs at the level of a *system*. It involves a large number of individuals working together in different units on different aspects of the very general problem of implementing new ideas.

by some combination of the two. In any case, interpersonal skills are an underlying condition for success.

Furthermore, I assume that the significance of interpersonal skills exceeds their specific role in the work aimed at gaining social acceptance for novel contributions. Clearly, my understanding of innovation as a collective, open-ended activity naturally calls attention to the necessity of interpersonal skills: How can highly *interdependent* individuals define and solve their open-ended tasks without a fair amount of communication skills? How can members of innovation projects *co-create* new knowledge through dialogue, discussion, and experience sharing without a minimum of interpersonal skills? Evidently, innovation success depends largely on the individual and collective capacity to play well *together*. Accordingly, I assume that interpersonal skills are an essential part of both individual and collective creativity. Such skills cannot be considered necessary for "innovation promotors" only.

Therefore, claiming that the traditional view of "creative" individuals is too limited to take account of the collective, open-ended nature of innovation efforts, I state that it is about time to challenge the stereotype figuring in creativity research. In this connection, a study of how individuals nurture innovation appears to be useful. Such a study would provide further knowledge of how interpersonal skills influence individual creativity and better insight into critical types of interpersonal skills.

When it comes to the components of individual creativity highlighted by both Amabile (1983a;1988;1996) and Csikszentmihalyi (1999;2001), I argue that *domain-relevant skills*, *creative thinking skills*, and *task motivation* should *all* be considered as major components of creativity.[90] In the following I focus on domain-relevant skills only.

The view that individual creativity relies heavily on knowledge of a domain is important.[91] It underscores that creativity is partly domain-specific, thereby challenging the classical understanding of creativity as a general characteristic applicable to most situations (Mayer, 1999). It also represents a powerful corrective to the mistaken belief that creativity is about creativity-relevant skills only.[92]

[90] In particular, I support Amabile's explicit attention to task motivation, and thus organizational conditions conducive for creativity. However, since task motivation is closely related to environmental conditions, and thus the *Press* facet of innovation and creativity, I shed light on task motivation through the review of work-environmental factors presented in Chapter 5. 4 The Press Facet of Innovation and Creativity.

[91] In the following I use Amabile's concept "domain-relevant skills" when referring to individual knowledge of a domain.

[92] E.g. the traditional understanding of creative persons as divergent thinkers able to produces many original and different ideas (Ref. Chapter 3.3).

Nevertheless, the very concept "domain-relevant skills" is somewhat ambiguous.[93] As long as individuals work within disciplinary context such as "mathematics", the identification of "domain-relevant skills" is straightforward: It is expertise on "mathematics". Clearly, you cannot make a creative contribution in the field of mathematics if you don't know anything of mathematics. Thus, in this case, the delimitation of "domain" and "domain-relevant" skills is easy. When I, on the other hand, view the concept "domain-relevant" skills in light of the complex industrial context of my case projects, the very delimitation of "domain" and "domain-relevant skills" becomes more difficult: What should be considered the "domain" in question? - The discipline, or field of study, in which an individual has been educated or the context defined by the innovation project?

These questions implicitly raise the question of which types of knowledge are required to make a creative contribution in innovation projects. Is the disciplinary knowledge possessed by an individual enough, or must individual experts also possess knowledge of what I simply denote the "problem context"? That is, what knowledge should the expertise component "domain-relevant skills" refer to when individuals work within a complex problem context? The importance of the *product champion*'s combined technical knowledge, market knowledge, and company knowledge suggests that it should include both disciplinary and relevant knowledge of the problem context.

Since neither Amabile nor Csikszentmihalyi explicitly discuss these questions, I argue in favor of shedding further light on this issue. I state that a study of salient characteristics of individual contributions fostering innovation would be useful. Such a study would provide important knowledge of the expertise component of individual creativity and the question of which knowledge and skills are required to make a creative contribution in a complex

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[93] The term "domain" may denote a field of study (an academic discipline), which is a body of knowledge which is taught or researched at the college or university level (Source: www.wikipedia.com downloaded 2008-04-04). Fields of study (domains) usually have several sub-disciplines. For instance, the domain of psychology covers a large number of sub-disciplines such as behavior science, clinical psychology, cognitive psychology, organizational psychology, and personality psychology. Apparently, Amabile (1983a; 1988; 1996) defines "domain" as a discipline in terms of a field of study or a sub-discipline within a larger field of study. For instance, she refers to the "domain of traditional social psychology" and "many disparate domains that all hold pieces of this puzzle" such as cognitive, personality, developmental, and industrial psychology (Amabile, 1996, p. xi).

Similar to Amabile, Csikszentmihalyi seems to equate "domain" with "discipline" or "field of study" (including sub-disciplines within larger fields of study). For instance, he mentions music, mathematics, religion, woodworking, gastronomy, and chemistry as examples of domains (Csikszentmihalyi, 1999, p. 315; 319. In "Creativity. Flow and the Discovery of Invention" he states that a domain consists of a set of symbolic rules and procedures (Csikszentmihalyi, 1996). He argues that mathematics is a domain but underscores that also narrower fields such as algebra and number theory can be seen as domains. Similarly, he thinks of companies and industries as domains, as reflected in his Motorola-example where he explicitly refers to management and the entire market of electronics as two relevant fields in question (Csikszentmihalyi, 2001, p.19).

problem context. In addition, it would shed further light on how interpersonal skills influence individual creativity, as previously suggested.

In turn, an investigation into salient characteristics of individual contributions promoting innovation would provide better insight into how creative performance in innovation projects can be enhanced by selective hiring of project members possessing high levels of relevant skills. Possibly, it would also give an indication of conditions facilitating the acquisition of relevant knowledge of the problem context. Therefore, I propose the following research question:

What are salient characteristics of individual contributions promoting innovation?

Research Question in Terms of the Person Facet of Innovation and Creativity

What are salient characteristics of individual contributions promoting innovation?

5.4 The Press Facet of Innovation and Creativity

5.4.1 Introduction

The purpose of the current chapter is to outline factors facilitating or inhibiting creativity (antecedent factors, ref. King, 1990). The list of antecedents builds on Nonaka and Takeuchi's (1995) emphasis of *intention, autonomy, creative chaos, redundancy,* and *requisite variety*, and Amabile's (2001) highlight of *challenge, freedom, resources, work-group features, supervisory encouragement,* and *organizational support.*[94]

5.4.2 Challenge

The most efficacious thing managers can do to stimulate creativity is to match people with the right assignment, that is, match people with jobs that play to their expertise and their skills in creative thinking and ignite intrinsic motivation (Amabile, 2001). Perfect matches stretch employees' abilities. The amount of stretch, however, is crucial: Not so little that they feel bored, but not so much that they feel overwhelmed and threatened by a loss of control. As such, Amabile calls attention to a prerequisite for *flow*, the state in which people are so involved in an action that nothing else seems to matter, driving them to creativity and outstanding achievement (Csikszentmihalyi, 1990). This enjoyable experience appears at the boundary between boredom and anxiety when the challenges are well balanced with the person's capacity to act. Activities conducive to flow are goal-directed and bound by rules that provide immediate feedback on performance (ibid.).

5.4.3 Creativity Encouragement

Supervisory Encouragement

Many researchers argue that a democratic, participative, and collaborative leadership style is conducive to innovation (King, 1990).[95] A participative style of decision-making is likely to increase the belief that an innovative idea will be accepted and valued (Farr and Ford,

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[94] These interrelated factors cover the individual, group, and organizational levels of creativity. However, in this chapter the factors themselves, not the level of analysis, are the center of attention.

[95] According to Van deVen et al. (1999), the type of leadership that is appropriate for an innovation changes over time. Use of economic and political incentives is often needed to get people to commit to an innovation effort. Those who become involved then need some structure and role and reciprocal responsibilities. Later, as euphoria turns to reality, and often disappointment, the need for support becomes paramount, as people need support to accomplish their aspirations.

1990). In addition, it helps innovation leaders reduce risk because it encourages completion of the assignment (Kanter, 1997). The involvement of others serves as a system of checks and balances for the project, reshaping it to make it more of a sure thing and putting pressure on people to follow through.

Furthermore, feedback and recognition from supervisors have been found to be an important facilitator of creativity (King, 1990). People can find their work interesting or exciting without a cheering section for some period of time. But in order to *sustain* such passion, most people need to feel as if their work matters to the organization or to some important group of people (Amabile, 2001). Managers in successful creative organizations rarely offer specific extrinsic rewards for particular outcomes. On the other hand, they freely and generously recognize creative work by individuals and teams often before the ultimate commercial impact of those efforts is known. Managers can support creativity by serving as role models, by persevering through tough problems, and by encouraging collaboration and communication within the team. Such behavior enhances all three components of creativity (ibid.).[96]

Organizational Support

Encouragement from supervisors certainly fosters creativity, but creativity is only truly enhanced when the entire organization supports it (Amabile, 2001). Most important, managers can support creativity by mandating information sharing and collaboration and by ensuring that political problems do not fester. Information sharing and collaboration support all three components of creativity.[97] Likewise, creativity-supporting organizations have appropriate systems or procedures that make it clear that creative efforts are a top priority. Among other things, they encourage *self-initiated activity*, *unofficial activity*, and *serendipity*[98] (Robinson and Stern, 1997), but avoid bribing people with money to come up with innovative ideas. Innovative organizations are also characterized by a risk-supporting climate in which failures are seen as opportunities for growth and learning (Barrett, 1998;

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[96] The three components of individual creativity are *domain-relevant skills*, *creativity-relevant skills*, and *task motivation* (Amabile, 1983a/b; 1988), ref. Chapter 5.3.

[97] The emphasis on collaboration and information sharing calls attention to the importance of *redundancy* to be discussed later, in Chapter 5.4.6.

[98] According to Robinson and Stern (1997), promotion of *self-initiated activity* implies an effective system for responding to employees' ideas. The majority of such ideas are self-initiated, meaning they are unanticipated by management. *Unofficial activity* is work done without direct official support and is what makes it possible for a company to go where it never expected to. It provides a safe haven for the strange and repellent, in which ideas have the opportunity to develop into something with clear potential. A *serendipitous activity* is one made by fortunate accident in the presence of sagacity (keenness of insight). Fortunate accidents can be promoted through strategies that provoke and exploit accidents. Sagacity can be promoted by expanding the company's human potential beyond its immediate needs.

Leonard and Swap, 1999; Amabile, 2001). Creativity-supporting managers recognize that innovation is a risky venture with no guarantee of where one's explorations will lead (Barrett, 1998). Therefore, innovative groups or organizations learn from experience by "failing forward" (Leonard and Swap, 1999), recognizing the difference between stupid mistakes and intelligent failures resulting from taking known (or anticipated risks) and caring deeply about a project (ibid.; Barrett, 1998). For instance, rather than ignoring mistakes, jazz musicians play with the ”wrong” notes, using them as creative departures for a different melody. Accordingly, an organizational culture that supports risk taking, collaboration, quality and security is likely to be an innovative and ”high-performance” culture as well (Leonard and Swap, 1999[99]). These values correlate positively with use of teams and information sharing, both of which suggest a high level of group interaction.

5.4.4 Resources

The two main resources that affect creativity are time and money (Amabile, 2001). Like matching people with the right assignments, deciding how much time and money to give a team or a project is a sophisticated judgment that can either support or kill creativity. Under some circumstances time pressure can heighten creativity by increasing the sense of challenge.[100] In contrast, organizations routinely kill creativity with fake deadlines or impossibly tight ones. The former create distrust and the latter burnout. In either case, people feel over-controlled and unfulfilled – which invariably damages motivation. When it comes to project resources, adding more resources above a ”threshold of sufficiency” does not boost creativity (ibid.).[101] Below a threshold, however, a restriction of resources can dampen creativity.

[99] Leonard and Swap (1999, p. 103) here refer to the work of Arad et al. (1997).

[100] Say, for instance, that a competitor is about to launch a great product at a lower price than you are offering or that society faces a serious problem and desperately needs a solution. In such situations, both the time crunch and the importance of the work legitimately make people feel that they must rush. Indeed, cases like these would be apt to increase intrinsic motivation by increasing the sense of challenge (Amabile, 2001).

[101] Amabile (2001) does not elaborate into the concept "threshold of sufficiency". I suppose that there is no consensus on what the ”threshold of sufficiency” means in different contexts or how to measure this threshold. For instance, King (1990) notes that the concept of ”slack” is as much psychological as financial; it is not just a matter of what resources that exist, but whether organizational decision-makers believe resources to be available for the organization. I assume this is the case with ”sufficient” resources as well.

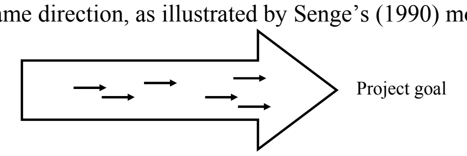
5.4.5 Alignment

Alignment and the antecedents outlined in the following chapters cover the key principles of holographic systems design (Morgan, 1997),[102] enabling organizational knowledge as a whole (Nonaka and Takeuchi, 1995).

There is consensus that shared commitment to clear goals, captured by terms such as *shared vision* (Senge, 1990), *alignment* (Robinson and Stern, 1997), and organizational *intention* (Nonaka and Takeuchi, 1995), promotes creativity in work groups and organizations.[103] An appreciation of an organization's vision creates a capacity for each person to embody and act in a way that represents the whole (Morgan, 1997). It provides focus and energy for learning (Senge, 1990). For this reason, work groups with clearly defined objectives are more likely to be effective and to develop new goal-appropriate methods of working (West, 1990). Similarly, a major characteristic of innovative organizations is clear organizational goals and visions to which most members of the organization are aligned (Kanter, 1983). A clearly stated mission is the only factor predictive of success at all stages of the innovation process (West, 1990). At the same time, visions must create space in which productive innovation can occur (Morgan, 1997). Thus, once the goals or mission are set, people should be given as much freedom as possible in how the goals are achieved (Amabile, 2001) (see Chapter 5.4.8 Autonomy). [104]

[102] These principles are: 1. Build the "whole" into the parts. 2. Redundancy. 3. Requisite variety. 4."Minimum Specs". 5. Learn to Learn (Morgan, 1997). I refer to the principles by using the terms "alignment", "redundancy", "diversity", "autonomy", and "creative chaos and collective reflection".

[103] I consider "alignment" as the most appropriate term here because I easily associate it with individuals heading in the same direction, as illustrated by Senge's (1990) model shown below.



[104] There seems to be some disagreement concerning the importance of involving subordinates in goal-or agenda-setting discussions. West (1990) argues that if a vision is to be a facilitator for innovation within a group it is important for it to be negotiated and shared. Visions of a group imposed by those hierarchically superior are unlikely to be facilitative of innovation. Much research indicates that involvement in goal setting fosters greater commitment to those goals (ibid.). Besides, a participative collaborative leader-style is conducive to creativity and innovation (Kanter, 1983; 1997; King, 1990; Farr and Ford, 1990). In contrast, Amabile (2001) argues that inclusion of subordinates in goal-or agenda-setting discussions does not necessarily enhance creative output. She emphasizes that she is not making the case that managers should leave their subordinates entirely out of such discussions. Her point is that whoever sets the goals, should also make them clear to the organization and make them remain stable for a meaningful period of time. It is difficult, if not impossible, to work creatively toward a target if it keeps moving. Thus, when it comes to granting freedom, the key to creativity is giving people autonomy concerning the means, but not necessarily the ends: "People will be more creative, in other words, if you give them freedom to decide how to climb a particular mountain. You needn't let them choose which mountain to climb" (Amabile, 2001, p. 6).

5.4.6 Redundancy

Redundancy, which in business organizations refers to intentional overlapping of information about business activities, management responsibilities, and the company as a whole, promotes collective knowledge creation (Nonaka and Takeuchi, 1995). When jobs are designed to reproduce overlapping knowledge, systems sustain flexible actions and mindful performance (Barrett, 1998). Without such excess capacity there is no room for innovation and development to occur; systems become fixed and static (Morgan, 1997). This is because overlapping knowledge creates redundant sets of information that permit people to identify with and take responsibility for the whole process rather than parts of the process. Redundancy encourages people to get involved in the challenges at hand, whatever they may be, and wherever they may come from, rather than focusing on narrow job descriptions and a “that’s not my responsibility” attitude (Morgan, 1997). Equally important, the sharing of redundant information promotes the sharing of tacit knowledge because individuals can sense what others are trying to articulate (Nonaka and Takeuchi, 1995). Redundancy of information brings about learning by intrusion into each individual’s sphere of perception.

Strategic rotation of personnel and “parallel processing”[105] are ways to build redundancy into the organization (Nonaka and Takeuchi, 1995; Morgan, 1997). These strategies help organizational members understand its business from multiple perspectives, making organizational knowledge more fluid and easier to put into practice (Nonaka and Takeuchi, 1995). Approaches enabling redundancy also promote *serendipity* and *within-communication* (Robinson and Stern, 1997), providing opportunities for unexpected connections between people, events, and ideas, and thereby unplanned communication.

The principle of redundancy raises the question of *how much* redundancy should be built into a system. This is where diversity in terms of *requisite variety* comes into play, providing a means of coping with the problem that everyone cannot be skilled in everything, as discussed next.

[105] The parallel processing approach implies that the same project is given to different teams that work independently and then come together to share progress, information, ideas, and insights (Morgan, 1997).

5.4.7 Diversity

The principle of requisite variety means that an organization's internal diversity must match the variety and complexity of the environment in order to deal with challenges posed by the environment (Nonaka and Takeuchi, 1995). Organizational members can cope with many contingencies if they possess requisite variety, which can be enhanced by combining information differently, flexibly, and quickly, and by providing equal access to information throughout the organization. Therefore, to maximize variety, everyone in the organization should be assured the fastest access to the broadest variety of necessary information going through the fewest steps (ibid.). Requisite variety also implies that whenever the necessary skills for dealing with the environment cannot be possessed by every individual, multi-disciplined groups composed of people who *collectively* have the required skills and abilities, are vital (Morgan, 1997).

The idea that diversity can promote creative and innovative outcomes in groups is widely accepted (Milliken et al., 2003). To say that a group is diverse is to say that it consists of members who differ from each other with respect to one or more features such as race, ethnic background, gender, average organizational tenure, or cognitive background variables. Cognitive diversity includes differences with respect to what group members know or how they think about problems as a result of their work experience, educational background, and training. As such, cognitive diversity largely covers differences with respect to group members' domain-relevant and creativity-relevant skills (Ref. Amabile, 1983a; 1988).

Emphasis on holographic systems design represents one approach to the issue of *diversity* in teams. Attention to diversity (variety) as a means of overcoming the tendency to uniformity in thinking is another. When working on complex, non-routine problems, groups are more effective when composed of individuals with diverse types of skills, knowledge, abilities, and perspectives (Leonard and Swap, 1999). The reason is that teams composed of people with various intellectual foundations and approaches to work, that is, different expertise and creative thinking styles, often combine and combust ideas in exciting and useful ways (Amabile, 2001). For instance, the introduction of alien perspectives – people who challenge the group by asking ”dumb questions”, making ingenuous observations, foster creativity (Leonard and Swap, 1999).

Yet, diversity appears to be a double-edged sword, increasing the opportunity for creativity as well as the likelihood that group members will be dissatisfied and fail to identify with the group (Milliken et al., 2003). Differences among group members can be sources of conflict and frustration in the early formative phase of group interaction, and this can carry over to subsequent operational and performance phases. Thus, although diversity can be beneficial for the creative process, this may occur only under conditions where the group process is carefully managed (Paulus and Nijstad, 2003).

Amabile (2001) argues that managers must make sure that three other work-group features accompany diversity. These factors support not only intrinsic motivation, but also expertise and creative-thinking skills. First, the members must share excitement over the team's goal (Ref. Chapter 5.4.5). Second, members must display a willingness to help their teammates through difficult periods and setbacks. Such supportive efforts are close to what jazz musicians do when they ”comp” a soloist. The “compers” agree to suspend judgment and to trust that whatever the soloist is doing right now will lead to something. They blend in to the flow and direction of the idea, rather that breaking it off in an independent direction (Barrett, 1998). When listening well to others' soloing, “compers” help soloists reach new heights. On the other hand, if everyone tries to be a star and does not engage in supporting the evolution of the soloist's ideas, the result is bad jazz. Accordingly, mutual support and “comping” behavior foster individual creativity. Third, every member of a team must recognize the unique knowledge and perspectives other members bring to the table (Amabile, 2001).[106] In other words, all team members must have a chance to solo from time to time. Well-performing self-directed work teams are often characterized by distributed, multiple leaderships in which people take turns leading various projects as their experience is needed (Barrett, 1998).

[106] Amabile (2001) emphasizes that the creation of mutually supportive groups with a diversity of perspectives and backgrounds requires managers to have a deep understanding of their subordinates. They must be able to assess them not just for their knowledge but also for their attitudes about potential fellow team members and the collaborative process, for their problem-solving styles, and for their motivational hot buttons. Thus, Amabile focuses on the challenge of recruiting the “right” people, apparently thinking that once a team with just the right chemistry has been put together, the group process will run smoothly without the conflicts and challenges pointed out above. I question this assumption, proposing that careful design of groups is a favorable, but not sufficient starting point. Careful group process management is also necessary.

5.4.8 Autonomy

The three principles for holographic systems design discussed above create a capacity to evolve (Morgan, 1997). But systems also need the *freedom* to evolve. They must possess a certain degree of "space" or *autonomy* that allows appropriate innovation to occur.

Discretion or freedom of choice is recognized as a positive antecedent of creative or innovative performance (King, 1990; Nonaka and Takeuchi, 1995; Barrett, 1998; Amabile, 2001). Research has shown that when the way a person performs a task is constrained or controlled, resulting in reduced autonomy, creativity is also reduced (Collins and Amabile, 1999). The most likely mechanism for the undermining effect of extrinsic constraints on creativity is an attentional one (ibid.). Extrinsic constraints can cause people to get focused on rules and controls instead of being absorbed and deal with the external challenges facing them. The negative impact of "trying" to attain specific results is well known in the performing arts. Trying to be "original" in theater sports, trying to produce a certain kind of sound, trying to paint a picture in accordance with a preconceived notion of what it "should" look like, blocks the process awareness necessary for creative achievements (Johnstone, 1979; Ristad, 1982; Csikszentmihalyi, 1990).[107] The decreased focus on the task contrasts with the concentrated attention and task involvement characteristic for high levels of intrinsic motivation (Collins and Amabile, 1999). Ergo, control easily results in an "attention bias" and hence reduces intrinsic motivation and creativity. In contrast, higher feelings of autonomy or freedom tend to be related to higher levels of intrinsic motivation and creativity (ibid.).

Autonomy fosters creativity because giving people freedom in how they approach their work heightens their intrinsic motivation and sense of ownership; self-determination is a major component of intrinsic motivation. Freedom regarding the process also allows people to approach problems in ways that make the most of their expertise and their creative thinking skills. Furthermore, an organization that secures autonomy is more likely to maintain greater flexibility in acquiring, interpreting and relating information, increasing the chance of introducing unexpected opportunities (Nonaka and Takeuchi, 1995). This is

[107] The point is "trying fails; awareness cures" (Ristad, 1982, referring to Tim Gallwey's philosophy in his book "Inner Game of Tennis"). Johnstone (1979, p 32) argues that in order to be spontaneous, people must not try to control the future, or to "win", but have "an empty head and just watch." Similarly, Ristad (1982, p. 41) underlines process awareness, referring to a master class in which two students improved their tone quality when they started to focus on how their tones *actually* sounded rather than how it "should" sound: "We talked about what was happening. When they changed their focus from over-determined effort to produce a certain kind of sound, to just being interested in the production of the tone in some fresh imaginative way that made use of their senses, they produced a tone in a more natural way."

because autonomy enables *play*. Play, the free spirit of exploration, doing and being for its own pure joy, gives people the chance to act in absence of extrinsic constraints (Nachmanovitch, 1990). Focus is on process, not results. Play fosters richness of response and adaptive flexibility, expanding our field of action. It supports creative-thinking skills, stimulating mental flexibility to question assumptions and have fun with ideas. Without play, creativity is not possible. Thus, autonomy encourages a *playful mood,* a prerequisite for developing new ideas and making one's way out of chaos (Kupferberg, 1996).

However, the principle of *minimum critical specification* suggests that autonomy is not about total freedom. The challenge is to define no more than is absolutely necessary to avoid the anarchy and the completely free flow arising when there are no parameters, on the one hand, and over-centralization on the other hand (Morgan, 1997). Emphasis is on facilitation, orchestration, and boundary management, helping people find and operate within a sphere of "responsible autonomy." This principle forms the basis for successful jazz improvisation (Barrett, 1998). Creativity in jazz bands is enhanced when emphasis is placed on coordinating action with minimal consensus, minimal disclosure and minimal simple structures (ibid.).[108] Accordingly, managers should channel the human flows of energy, but not micromanage those flows (Leonard and Swap, 1999).

5.4.9 Creative Chaos and Reflective Practice

Fluctuation and creative chaos stimulate organizational knowledge creation, causing a ”breakdown” of routines, habits or cognitive frameworks (Nonaka and Takeuchi, 1995). Such a breakdown provides members of groups and organizations with the opportunity to reconsider fundamental thinking and perspectives. As such, double-loop learning is fostered (Argyris and Schön, 1996). Chaos is generated naturally when the organization faces a real crisis. It can also be generated intentionally. Jazz musicians cultivate such ”provocative competence”, deliberately challenging habitual patterns and creating

[108] Concerning the relationship between organizational structure and innovation, there is consensus that strongly bureaucratic organizations with a rigid and tall hierarchy and with much compartmentalization of function, information, and responsibility will tend to stifle innovation. In contrast, organizational structures that permit relative autonomy for lower levels and relative interdependence for various functional groups at the same level in the organization have been found to be associated with high levels of innovativeness (Farr and Ford, 1990). Other researchers such as Zaltman et al. (1973) have noticed that the variables centralization, formalization, and complexity have contrasting effects at the initiation and implementation stages of the innovation process (the so-called ”innovation dilemma”): Initiation is facilitated by low levels of centralization and formalization and high levels of complexity, whereas implementation is facilitated by high centralization and formalization and low complexity. Empirical evidence regarding the ”innovation dilemma” does offer some support, but it is not full and unambiguous (King, 1990). Nonaka and Takeuchi (1995) propose a third structure, the hypertext structure in which a non-hierarchical, self-organizing structure promoting socialization and externalization, works in tandem with its hierarchical structure facilitating combination and internalization.

incremental disruptions as occasions for stretching into unfamiliar territory (Barrett, 1998). Miles Davis surprised his band by disrupting their routines and stretching them beyond comfortable limits, calling unrehearsed songs and familiar songs in foreign keys. Similarly, leaders of an organization sometimes try to evoke a ”sense of crisis” by proposing challenging goals. This intentional ”creative chaos” increases tension within the organization and focuses attention on defining the problem and resolving the crisis situation (Nonaka and Takeuchi, 1995).

Still, the benefits of ”creative chaos” can only be realized when organizational members have the ability to reflect upon their actions. Without reflection, fluctuations tend to lead to ”destructive chaos.” Thus, individual and collective reflection in and on action, including questioning and reconsidering existing premises, is a prerequisite for making chaos truly ”creative” - and for enhancing the knowledge creation capacity of organizations and groups in general (Schön, 1983; Philips, 1988; Senge, 1990; Nonaka and Takeuchi, 1995; Argyris and Schön, 1996).[109]

5.4.10 Summary Discussion and Formulation of Research Questions

Amabile (2001) and Nonaka and Takeuchi (1995) represent complementary, partially overlapping research on antecedent factors. Where Amabile largely focuses on the motivational impact of work-environmental factors, Nonaka and Takeuchi (1995) call attention to the impact of conditions enabling collective knowledge creation as a whole. In sum, the contributions cover several factors that can serve as guidelines for the design of creativity-boosting working environments. At the same time, the works reveal that more empirical research is needed to fully understand the real impact of these factors.

Nonaka and Takeuchi’s emphasis on the five enabling conditions first and foremost reflects an intellectual fascination with holographic systems design. They do not provide sound empirical evidence for how and why these conditions encouraged knowledge creation in Japanese companies. Data are largely presented through brief references to the very presence of conditions in pertinent empirical examples.[110] As such, Nonaka and Takeuchi do not prove their assertions in a convincing way.

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[109] In turn, the emphasis on institutionalized”reflective practice” calls attention to the need for arenas for dialogue, or ”high-density fields of interaction” (Nonaka and Takeuchi, 1995).

[110] ”Here we can also observe the five enabling conditions at work” is a typical introductory phrase followed by a litany of brief examples.

The other works referred to under the headings of the five enabling conditions (*alignment*, *redundancy*, *diversity*, *autonomy*, *creative chaos and reflective practice*) represent empirically grounded research or theoretical statements illustrated by anecdotal examples. In sum, they support the argument *that* a particular condition is important, but do not elaborate why this is so. Accordingly, there is need for more research on the relationship between creativity and the antecedents outlined above.

Amabile (2001) presents solid empirical research. Her social-psychological approach to creativity is based on experimental and non-experimental studies largely focusing on how social-environmental factors influence individual creativity through task motivation (Amabile, 1996). Amabile (2001) suggests that several factors support all the three components of individual creativity (domain-relevant skills, creativity-relevant skills, task motivation), but does not provide sound empirical evidence for this assumption. In fact, there is little research on how work-environmental factors influence individual domain- and creativity relevant skills (Amabile, 1996). Similarly, there is little research on how such factors affect *collective* creativity. Nonaka and Takeuchi (1995) may be regarded as a relevant contribution here, but is empirically weak.

So, summing up, I conclude that there is a need for more research on how work-environmental factors influence creativity, in particular at the collective level. Therefore, a study of the relationship between antecedent factors and collective creativity appears useful. It would provide better insight into how collective creativity can be enhanced, thereby shedding further light on organizational conditions for innovation. In this connection, I think attention to *supervisory encouragement and organizational support*, *diversity*, and *redundancy* form a proper starting point.

Supervisory encouragement and *organizational support* naturally bring the social, collective dimension of creativity, not least the importance of *interpersonal skills*, into focus (Ref. Chapter 5.3). For this reason, studying how these antecedents support collective creativity would contribute to a deeper understanding of creativity and innovation as collective phenomena. Moreover, I assume that attention to the factors in question would also shed light on other antecedents such as *resources* and *autonomy*. Clearly, the current literature review suggests that creativity-boosting managers allocate sufficient time and money and provide people with “responsible autonomy”. Therefore I propose the following research question:

How do supervisory encouragement and organizational support promote collective creativity in innovation projects?

Furthermore, the principle of requisite variety reflects attention to innovation as a complex activity requiring the involvement of specialists who collectively possess a sufficient diversity of expertise. A study highlighting diversity would thus provide better insight into how diverse competence promotes collective creativity.[111] The following research question thus appears relevant:

How does diversity in competence promote collective creativity in innovation projects?

The principle of *redundancy* points up that diversity is of little value if people are not allowed to adequately share information. Chapter 5.4.7 briefly mentions ways to build redundancy into the organization, such as strategic rotation of personnel and parallel processing. The attention to redundancy-boosting strategies suggests that the very choice of approaches and work forms is vital for innovation success. Clearly, diversity is not only about composing an ensemble of specialists who collectively have the required skills and expertise. To benefit from diversity, the players must also collaborate and interact in ways that make the most of their overall expertise. Thus, I argue that a closer examination of work forms and approaches in innovation projects would be useful. Such a study would provide important knowledge on strategies boosting collective creativity and thus the likelihood for innovation success. I therefore propose the following research question:

What approaches and work forms increase the likelihood for innovation success?

To summarize, my research questions in terms of the press facet of innovation and creativity are:

[111] Following Nås (2000), I consider competence as the ability to solve simple and complex practical tasks by using relevant knowledge and skills. That is, competence is directly related to a particular task, and to the level of that task. As such, I think of competence as similar to Amabile's (1983a/b; 1988; 1996) concept of domain-relevant skills (Ref. Chapter 5.3) and as synonymous with expertise.

Research Questions in Terms of the Press Facet of Innovation and Creativity:

How do supervisory encouragement and organizational support promote collective creativity in innovation projects?

How does diversity in competence promote collective creativity in innovation projects?

What approaches and work forms increase the likelihood for innovation success?

5.5 The Product Facet of Innovation and Creativity

5.5.1 Introduction

The *Product* facet of creativity and innovation was thoroughly discussed in Chapters 2.2 and 3, respectively, in connection with the reviews of criteria of innovations and creative products. In addition, the facet was highlighted in Chapter 2.3 Radical and Incremental Innovation. Therefore, this chapter largely presents a summary of earlier discussions. I here treat "creative products" and "innovations" (as results of innovation processes) as synonyms.

5.5.2 Discussion and Formulation of Research Question

Several researchers point out that the analysis of creative products forms the basis for all studies of creativity, providing external criteria to which researchers can compare other methods of measuring creativity in order to establish validity. (Ekvall, 1979; Plucker and Renzulli, 1999). For this reason, product definitions are regarded as superior to the other types of creativity definitions (Ekvall, 1979). "Products" are usually conceived in its widest sense, covering all kinds of observable results arising from thinking- and work processes (Ekvall, 1979; Amabile, 1988; Boden, 1999). I refer to innovations as "products or processes", where "products" refer to all kinds of products including aluminum sections as well as jazz concerts, while "processes" applies to any kind of method of production/management, etc.

There is considerable agreement among researchers that creative products and innovations must be novel and appropriate (Ref. Chapters 2.2 and 3). Several researchers also claim that creativity should be limited to difficult tasks or problems (Ref. Chapter 3).[112] Still, despite the widespread consensus regarding appropriate novelty, the interpretation of "novelty" is subject to great controversy in terms of frame of reference and degree of novelty (Ref. Chapter 2.2). Researchers propose different answers to questions such as "What is new?", "Compared to what is something new?", "To what extent is something new?", and "To whom is something new?" Similarly, differentiation of radical from incremental innovation is subject to great ambiguity (Ref. Chapter 2.3). Neither a

[112] As discussed in Chapters 2.2 and 3, I argue that novelty, appropriateness, and the involvement of an open-ended task form criteria of creative products.

unified theory nor a consensual agreement of classification criteria exists. Where some researchers focus on one single criterion, others highlight a group of features. At the same time, opinions on the relative importance of the respective criteria differ. Thus, by revealing *interpretative flexibility* (Pinch and Bijker, 1987) my conceptual study (Ref. Chapters 2 and 3) points out that judgment of creativity and innovativeness is a matter of social construction (Berger and Luckmann, 1966/2004): Whether a product is creative or not does not depend on its own qualities, but on the judgments that social systems make about it (Csiskzentmihalyi, 1999). As such, the apparent assumption that products in themselves provide clear, unbiased criteria is simplistic: It is not possible to articulate objective criteria for identifying products as "creative", "innovative", or "radically" innovative. For this reason, I argue that consensual definitions based on the subjective assessments by appropriate observers[113] in the field represent a sound strategy in empirical research (Ref. Amabile, 1988; 1996). As long as there is consensus in experts' judgments of creativity, innovativeness, or the "radicalism" of innovations, we can reasonably accept those ratings as valid statements (Ref. Chapter 2.3).

Nevertheless, taking account of the great conceptual ambiguity revealed in Chapter 2, I assume that sometimes it is not possible to obtain high levels of agreement in subjective judgments of innovativeness.[114] Evidently, the use of expert judges is not without problems (Plucker and Renzulli, 1999). The determination of the necessary level of expertise of judges depends on a variety of factors, including the skills of the subjects, the target domain, and the purpose of the assessment. In addition, appropriate observers do not possess objective evaluation standards. Rather their judgments rely on past experience, training, cultural biases, current trends, personal values, and idiosyncratic preferences (Csikszentmihalyi, 1999). As such, we cannot take a consensual agreement among appropriate observers for granted. This argument influenced my decision to drop the explicit attention to "radical" innovation in this thesis. In Chapter 2.3 I argued that in order to find out whether any of the case projects provided examples of radical innovation, I would have to study how project participants independently perceived the project in light of this innovation label. Since I could not take a consensual agreement for granted, I had no guarantee that any of the projects could be considered as cases of "radical" innovation. In

[113] As discussed earlier, appropriate observers (or experts) are those familiar with the domain in which the outcome is produced (Ref. Amabile, 1988; 1996)

[114] This assumption contradicts Amabile's (1996) findings of quite high levels of agreement in subjective judgments of creativity. Still, the conceptual ambiguity and controversy concerning the interpretation of "novelty" and definition of "radical" innovation suggests that appropriate judges may base their subjective assessments on different criteria.

fact, the great conceptual ambiguity concerning radical and incremental innovation made me assume that a study of how project participants perceived the projects' "radicalism" would reveal variance rather than consensus; when innovation labels mean different things to researchers, they probably mean different things to industrial people as well. I hence concluded that it was uncertain whether any of my case projects would be regarded as cases of "radical" innovation. Still, I consider a study of how project members assess the "radicalism" of the project outcome as highly relevant in light of the thesis' attention to organizational conditions for innovation.

As discussed earlier, classification of innovation is regarded as essential for effective innovation management since different kinds of innovation require different management approaches. When viewing this statement in light of the findings revealed in Chapter 2.3, it becomes evident that the lack of unified definitions makes the choice of appropriate approaches difficult in practice. This observation suggests that innovation managers should recognize the importance of collective reflections on innovation labels. Without such debates, innovation labels can hardly be of any use when it comes to effective innovation management. I argue that a study of how project members assess the project outcome in light of the radical-incremental dimension, including an examination of the underlying subjective criteria, could shed further light on the need for collective reflections on relevant concepts. If the overall subjective assessments display considerable disagreement, the study will represent a powerful argument in favor of emphasizing the necessity of explicit debates concerning definitions and criteria of concepts such as "innovation", "radical" innovation, and "incremental" innovation.[115] Clearly, no open-ended tasks can be successfully managed without emphasis on problem definition. This applies to the open-ended tasks of becoming "innovative", or aiming to stage for "radical" innovation as well. Therefore, I propose the following research question:

How do project members assess the outcome of the project in light of the concepts incremental and radical innovation?

[115] In addition, the study will strongly call into question the assumption of unison agreement underlying most existing innovation research (King and Anderson, 1990). For instance, Ørstavik's (2000) study of "successful" innovations is based on interviews with *one* informant in each company, usually the person responsible for product development.[115] Apparently, Ørstavik and other researchers undertaking similar studies assume that subjective assessments made by one relevant "judge" represent the common opinion among all relevant judges in a company.

Research Question in Terms of the Product Facet of Innovation and Creativity

How do project members perceive the outcome of the projects in light of the concepts incremental and radical innovation?

5.6 The Process Facet of Creativity and Innovation

5.6.1 Introduction

In the current chapter I approach the process facet of creativity and innovation from two angles: 1) The temporal sequence of events, and 2) Organizational learning and knowledge creation. I highlight how innovation processes unfold over time through an outline of the MIRP[116] "fireworks" model. The reason for devoting attention to this model is twofold. First, the MIRP model is a comprehensive, empirically grounded process theory of innovation. Second, as opposed to previous process models described in the literature, the model accounts for the complexity and uncertainty in innovation processes (Van de Ven et al., 1999).[117] It emphasizes that innovation is an emergent process, an exploratory journey into the unknown process wherein novelty emerges. As such, the MIRP model is relevant in light of my claim that innovation efforts deal with open-ended problems.

When it comes to organizational learning and knowledge creation, I shed light on Argyris and Schön (1996) and Nonaka and Takeuchi (1995) because these works are important "classics" of relevance for my study. In addition, I review perspectives on improvisation in jazz and drama. These contributions complement the other works by showing how people create new knowledge in highly ambiguous, uncertain, complex, and uncontrollable situations.

5.6.2 The MIRP Process Model of Innovation

The MIRP studies were undertaken with an aim to understand how innovations develop from concept to reality ("The Innovation Journey").[118] The researchers found that innovations developed in a messy, complex progression of events (Van de Ven et al.,

[116] The Minnesota Innovation Research Program (MIRP) involved more than 30 researchers who undertook longitudinal field studies examining 14 different technological and administrative innovations (new procedures, policies, and organizational forms) in both industry and the public sector during a ten-year period from 1983 to 1993 (Van de Ven et al., 1999).

[117] According to Van de Ven et al. (1999), Scroeder, Van de Ven, Scrudder, and Polley (1989) did a review of process models, comparing literature from group development models, decision process models, organizational planning models, organizational change and development models, and innovation process models. None of the reviewed models were found adequate for describing the developmental pattern of innovation processes in organizations.

[118] The MIRP researchers defined the innovation journey as a sequence of events in which new *ideas* are developed and implemented by *people* who engage in *relationships* with others and make the adjustments needed to achieve desired *outcomes* within an institutional and organizational *context* (Van de Ven, 1999). Therefore, a more specific formulation of their research aim was to understand how changes in innovation ideas, outcomes, people, transactions, and contexts unfold over time.

1999). At the same time, they observed a dozen common elements across different organizational structures and settings, pertaining to the *initiation*, *development*, and *implementation* periods of innovations. The twelve process characteristics and the emerging "fireworks" process model are shown in Figure 5.6.1[119] (ongoing operations process in the direction of A, the launched innovation in the direction of B).

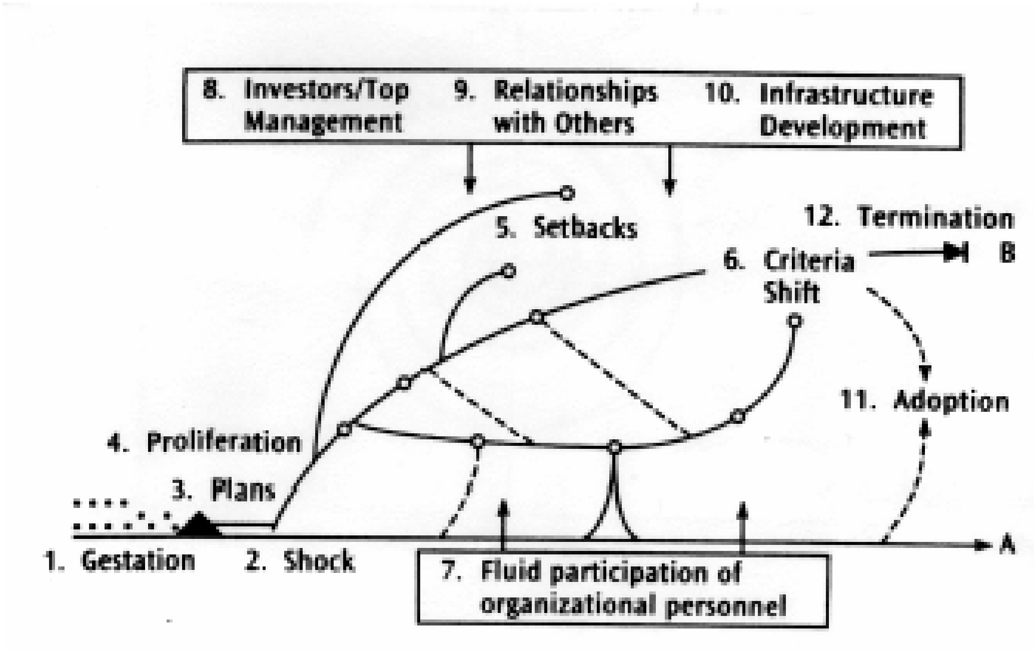

Figure 5.6.1 Key Components of the Innovation Journey (Van de Ven et al., 1999)

The *initiation* period is the period in which activities and events occur that set the stage for launching efforts to develop an innovation. It includes three elements: *Gestation*, *shock*, and *plans*. According to Van de Ven et al. (1999), innovations are not initiated on the spur of the moment, by a single dramatic incident, or by a single entrepreneur. In most cases, there is an extended *gestation* period lasting several years in which seemingly coincidental events occur that precede and set the stage for the initiation of innovations. Concentrated efforts to initiate innovations are triggered by *shocks* from sources internal or external to the organization such as new leadership or an impending loss of market share. Next, *plans* are developed and submitted to resource controllers to obtain the resources needed to launch innovation development.[120]

The *development* period is the period in which concentrated efforts are undertaken to transform the innovative idea into a concrete reality. *Proliferation*, *setbacks*, and *criteria*

[119] According to Van de Ven et al. (1999), the process characteristics are not the same in all innovations. They are expected to be more pronounced for innovations of greater novelty, size, and temporal duration.
[120] In most cases, the plans served more as "sales" vehicles than as realistic scenarios of innovation development.

shifts are common process characteristics here. The MIRP researchers observed that when development activities begin, the initial innovative idea soon proliferates into numerous ideas and activities that proceed in divergent, parallel, and convergent paths of development.[121] *Setbacks* and mistakes are frequently encountered because plans go awry or unanticipated environmental events significantly alter the basic assumptions of the innovation. To compound the problems, the *criteria* of success and failure often change. They differ between resource controllers and innovation managers, and diverge over time, often triggering power struggles between insiders and outsiders. *Fluid participation* of innovation personnel, frequent *involvement of investors and top managers, development of relationship with other organizations,* and *infrastructure development* are other process characteristics found in the development period. Finally, the implementation/termination period involves adoption and implementation of the innovation by linking and integrating the “new” with the “old”, or by reinventing the innovation with the local situation. Innovations stop when implementations or resources run out.

Van de Ven et al. (1999) emphasize that the ”seemingly random” process of innovation development is not a random sequence of change, or “blind” events. Rather, it reflects a non-linear dynamic system consisting of a cycle of divergent and convergent activities that may be repeated over time and at different organizational levels if enabling and constraining conditions are present.[122] Yet, the most striking characteristic of the innovation process concerns the implications of the divergent-convergent cycle: Whatever route is taken, the innovation journey crosses a rugged landscape that is often highly ambiguous, unpredictable, uncontrollable, and involving a good deal of luck; the innovation journey is

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[121] According to Van de Ven et al. (1999), this proliferation of activities over time appears to be a pervasive but little understood characteristic of organizational change and innovation processes, accounting for much of the apparent complexity of the “fireworks” model.

[122] This divergent-convergent cycle is the underlying dynamic that explains the development of corporate cultures for innovation, learning among innovation team members, leadership behavior of top managers or investors, building relationships, and joint ventures with other organizations and developing an industrial infrastructure for innovation. Resource investments and organizational structures enable this innovation cycle, while external institutional rules and internal focus draw the boundaries of the journey.

Divergence, triggered by the infusion of resources into the system, involves branching behavior that explores and expands in different directions. It increases the complexity of a system and tends to follow a random or chaotic process. In contrast, *convergent* behavior, triggered by external and internal dynamics, is an integrating and narrowing process focusing on testing and exploiting a given direction. It reduces the complexity of a system and moves it toward a periodic pattern of quasi-equilibrium (Van de Ven et al., 1999). Taking dynamic systems theory as their starting point, the authors point out that a chaotic process is less “random” than “random” processes. Chaos, in its correct mathematical form, implies a state of bounded order and predictability of temporal pattern, but not path. Relative to randomness, chaos therefore reduces confusion because future action is in large part deterministically generated based on the current state, that is, people use the current situation to guide their next steps. Thus, a chaotic process appears to share similarities with improvisation (see Chapter 5.6.3) an uncharted river (Van de Ven et al., 1999).[123] People are neither able to know the final destination, nor are they able to be in control of the journey (Stacey, 1996). Therefore, Van de Ven et al. (1999) advise managers to learn to "go with the flow", that is, learn to manoeuvre through the innovation process without trying to control the "uncontrollable". Still the MIRP researchers neither describe how managers actually manoeuvre the innovation journey nor discuss how they can develop appropriate manoeuvring skills. This is a major shortcoming of their contribution to the field of innovation. In contrast, perspectives on improvisation in jazz and drama provide valuable insight into how managers can manoeuvre innovation processes. As Barrett (1998, p.5) claims: "*Jazz players do what managers find themselves doing: fabricating and inventing novel responses without a prescripted plan and without certainty of outcomes: discovering the future that their action creates as it unfolds*." In fact, the jazz band is a prototype organization designed for maximum learning and innovation (e.g. Weick, 1998; Barrett, 1998; Alterhaug, 2000). Jazz musicians (as well as improvising actors) practice the art of leaping into the unknown while simultaneously being expected to create something new and coherent. In particular, they train the essential skill of suspending control and surrender to the flow of ongoing events. As such, works in the fields of jazz and drama stand out as a relevant contribution to understanding the *Process* facet of innovation.

5.6.3 Improvisation

What is Improvisation?

In their work on dramatic improvisation, Frost & Yarrow (1990) argue that improvisation is not just a style or an acting technique; it is a dynamic *principle* operating in many different spheres; a paradigm for the way in which humans reflect and create what happens. Improvisation is "the skill of using bodies, space, all human resources, to generate a coherent physical expression of an idea, a situation, a character (even, perhaps, a text); to do this spontaneously in response to the immediate stimuli of one's environment, and to do it *à l'improviste*: as though taken by surprise, without preconceptions" (Frost & Yarrow, 1990, p. 1). Weick (1998) gives a similar description, explaining that the word

[123] Stacey (1996) presents a similar argument in his description of the processes of creativity and innovation. He writes: "…these are the very conditions required for creativity, *an exciting journey into open-ended evolutionary space with no fixed, predetermined destination*. The whole universe, it seems, is lawful and yet it has freedom of choice. The price for this freedom is *an inability to know the final destination or to be in control of the journey*." (Stacey, 1996, p. 13, italics is mine)

improvisation originates from the word “proviso” that means to make a stipulation beforehand, to provide for something in advance, or to do something that is planned for. *Im*proviso, or the opposite of proviso, thus implies that improvisation deals with the unforeseen and works without a prior stipulation.

On the other hand, improvisation is *not* about making something out of nothing. Successful improvisation presupposes “something to improvise on” and a great amount of practice (Weick, 1998). A sole emphasis on the spontaneous, intuitive nature of improvisation thus overlooks important features of improvisation.

Therefore, Weick speaks in favor of the following definition:

> …*Improvisation involves reworking precomposed material and designs in relation to unanticipated ideas conceived, shaped, and transformed under the special conditions of performance, thereby adding unique features to every creation* (Weick, 1998, p. 544[124])…

Keys to Successful Improvisation

The fact that improvisation involves exploring, continual experimentation, and tinkering with possibilities without knowing where one’s queries will lead or how action will unfold, implies that excitement and risk of failure is inherent in improvisation (Frost and Yarrow, 1990; Barrett,1998).Therefore, learning to improvise means learning to play, preparing to be spontaneous, and developing the capacity to embrace errors as a source of learning (Johnstone, 1979; Frost & Yarrow, 1990; Nachmanovitch, 1990, Barrett, 1998). This is often a difficult process because improvisation challenges people’s urge to be in control of situations, and thus also challenges their fear of failure.[125] According to Frost and Yarrow (1990), the hardest thing to learn about improvisation is to learn that “failure doesn’t matter”.[126]

Keith Johnstone, “the father of theatre sports”, argues that spontaneity presupposes a strong supportive group climate in which the members look after one another, and in which failure is not frightening (Johnstone, 1979). Besides, in order to learn spontaneity, we must not try to control the future, that is, try to “make it happen” (Johnstone, 1979; Ristad, 1982; Frost and Yarrow, 1990). Johnstone (1979) reports that ordinary people asked to improvise often block their imagination because they try to “think up” some “original” idea. Instead,

[124] Weick (1998) refers to Berliner (1994, p. 241)

[125] Argyris and Schön (1996) argue that people are programmed to try to preserve control over the situation when faced with threatening and embarrassing issues (as will be discussed later in this chapter).

[126] Fear of failure is recognized as a major creativity block (Johnstone, 1979; Ristad, 1982; Kupferberg, 1996; Frost and Yarrow, 1990; Barrett, 1998; von Euch, 1998).

people should learn to accept their first idea, realizing that this makes them more inventive. A good improviser accepts anything that happens, including what his imagination gives him and the offers given by others. He is a *bricoleur,* making use of whatever is at hand (Barrett, 1998). Schön (1983) indicates that a similar attitude is embodied in the capacity of practitioners to reflect-in-action, and to keep inquiry moving in on-the-spot situations of uncertainty, uniqueness, and conflict. When action produces unintended effects, the practitioner listens to the situation's back-talk, "and as *he appreciates what he hears*, he reframes the situation once again" (Schön, 1983, p.132, italics are mine). It follows that good improvisers develop action, whereas bad improvisers block further progress (Johnstone, 1979). Ergo, an essential element in learning improvisation is to practice *process awareness* and recognize that what matters is "to listen, to watch, to add to what is happening rather than subtract from it" (Frost and Yarrow, 1990, pp. 2-3): "Trying fails; awareness cures" (Ristad, 1982, p.40). It is also essential to embrace errors as a source of learning, and legitimate serious play as a fruitful, meaningful activity (Barrett, 1998).

Weick (1998) calls attention to *practice*, *forms* and *memory* as key determinants of successful jazz improvisation. A stunning jazz performance presupposes extensive investment in *practice*, listening and study.[127] As such, a jazz musician is more accurately described as a highly disciplined "practicer" than as a practitioner. Next, improvisation does not materialize out of thin air: "You've gotta improvise on something."[128] Jazz improvisation materializes around a simple melody whose *form* provides the pretext for real-time composing. It is real-time composing that begins with embellishments of a simple model, but increasingly feeds on these embellishments to move farther from the original model and closer to a new composition.[129] Improvisation, thus, is a guided activity based on retrospective sense making. Jazz musicians enter into a dialogue with their material; prior selections begin to fashion subsequent ones as themes are aligned and reframed in relation to prior patterns (Barrett, 1998). As new phrases or chord changes are introduced, the

[127] Learning to play jazz is a matter of learning the theory and rules that govern musical progressions, and jazz musicians "hang around" and learn from others by being members of communities of practice (Barrett, 1998).

[128] Weick (1998, p. 546) cites the bassist-composer Charles Mingus, who insisted "you can't improvise on nothing; you've gotta improvise on something".

[129] In this connection, Weick (1998) points to different degrees of improvisation representing a continuum ranging from "interpretation" through "embellishment" and "variation" ending in "improvisation". This progression implies increased demands on imagination and concentration. The three first labels describe approximations to improvisation focusing on both connections to the past and on the original model that is being embellished. Improvisation, in contrast, means "transforming the melody into patterns bearing little or no resemblance to the original model…" (Weick, 1998, p.545). In other words, to improvise is to engage in more than paraphrasing, ornamentation, or modification.

improviser plays with various possibilities, making connections between the old and the new material. It follows that to improve improvisation is to improve *memory*, gaining retrospective access to a greater range of resources (Weick, 1998). As Johnstone (1979) puts it:

> *…The improviser has to be like a man walking backwards.*
> *He sees where he has been, but pays no attention to the future. His story can take him anywhere, but he must still "balance" it, and give it shape, by remembering incidents that have been shelved and reincorporating them…* (Johnstone, 1997, p. 116)

Weick (1998) argues that the retrospective aspect of improvisation suggests a new understanding of organized action. It underlines that intention is loosely coupled to execution, that creation and implementation are not necessarily separated in time, and that sense-making rather than decision-making, is embodied in improvisation. Barrett (1998) calls attention to the fact that jazz bands practice the following improvisation-boosting principles: *provocative competence* (challenges habits and conventional practices), *minimal structures,* and *alternating between soloing and supporting* (shared leadership and "accompaniment").[130] Yet, the most striking characteristic of successful jazz improvisation is the ongoing give and take between members (ibid.). Players are in continual dialogue and exchange with one another, negotiating toward dynamic synchronization. They are engaged with continual streams of activity: Interpreting the way others are playing, anticipating the progress based on harmonic patterns and rhythmic conventions, while simultaneously attempting to shape their own creations and relate them to what they have heard. Thus, in order for jazz to work, players must develop a remarkable degree of empathic competence. It follows that the quality of a jazz performance relies not only on the band members' individual competence, but also on their collective capacity to play well *together*. A jazz band cannot achieve the desired "groove"[131] without a mutual orientation to the beat, including mutual listening, support, and "comping"; they have to connect with one another (Barrett, 1998).

[130] These principles cover the following principles of holographic systems design: "learn to learn", "minimum specs", and "the importance of redundancy" (Ref. Morgan, 1997).
[131] "Groove" refers to the dynamic interplay within an established beat. It occurs when the rhythm section "locks in" together, when members have a common sense of the beat and meter. Establishing a groove, however, is more than simply playing the correct notes. It involved a shared "feel" for the rhythmic thrust. (Barrett, 1998)

Characteristics of Improvisational Creativity

Sawyer (1992) approaches jazz improvisation by bringing the concept of *improvisational creativity* into focus. Unlike *compositional* creativity that involves a long period of creative work leading up to a creative product, the salient feature of improvisational creativity is a *co-occurrence* of the process and the resulting product. Sawyer argues that jazz performances reflect five characteristics of improvisational creativity. First, jazz involves real-time social interactional influences including the other band members and the audience. Next, jazz is characterized by a complex interaction of both conscious and non-conscious processes during performance. As opposed to the traditional two stage models of creativity in which a subconscious idea generation phase (ideation) is followed by an assessment of ideas (selection), ideation and selection in jazz can occur at both conscious and non-conscious levels, and in some cases simultaneously. Third, in jazz performance it is difficult to identify a "unit of ideation," i.e. a single, quantifiable, creative idea, because creativity occurs on many structural levels. Fourth, jazz is characterized by the tension resulting from conforming to the rules of the domain, while simultaneously innovating, i.e. "breaking the rules". [132] Finally, jazz performance concerns the individuals striking a balance between their own personally developed structures and the need to continually innovate at a personal level (ibid.).

5.6.4 Organizational Learning and Knowledge Creation.

Argyris and Schön (1996) define organizational learning as organizational inquiry that results in a change in the organizational theory-in-use.[133] *Single-loop* learning is instrumental learning that changes strategies of action or their underlying assumptions, but not the values or norms themselves. In contrast, *double-loop* learning changes both the values of a theory-in-use and its strategies and assumptions. The quality of double-loop learning is dependent on the larger organizational system promoting or inhibiting organizational inquiry. In turn, the organizational learning system is dependent on individual theories-in-use that reinforce and are reinforced by the system.

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[132] According to Sawyer (1992), the domain represents the "raw materials" available to the creative individual, and the rules and procedures that can be used to combine them.

[133] Building on Dewey's works, Argyris and Schön understand *organizational inquiry* as the intertwining of thought and action carried out by individuals in interaction with one another on behalf of the organization to which they belong. An *organizational theory-in-use* is an organizational theory-of-action (comprising strategies of action, the values governing the choice of action, and their underlying assumptions) that is implicit in the performance of that pattern of activity.

Argyris and Schön's theory sheds further light on why most people find the improvisation imperative "Suspend control! Surrender to the flow!" difficult. The researchers point out that people are programmed with inquiry-inhibiting Model I theories-in-use. Faced with threatening and embarrassing issues, people think and act in accordance with this theory, trying to preserve control over the situation, other people, and their own feelings. The Model I theories-in-use cause defensive reactions, creating self-reinforcing feedback loops[134] strengthening the strategies of action and the Model-1 theories- in-use, producing the inquiry-inhibiting *O-I learning system*. Consequently, organizations suffer from a limited learning capacity characterized by *skilled incompetence* and *skilled unawareness.*[135] The key to overcoming this disability is *deuterolearning*, that is, double-loop learning in *processes* of inquiry, facilitating a shift towards inquiry-enhancing theories-in-use.[136] Deuterolearning implies a shift from the Model-I theory-in-use whose governing variables are goal achievement, win/loose orientation, avoidance of negative feelings, and rationality, to Model-II theory-in-use governed by valid information, free and informed choice, and internal commitment; a change from defensive to productive organizational theories-in-use; and consequently a shift from the O-I towards the O-II-learning system.[137]

Where Argyris and Schön emphasize high-quality learning systems, Nonaka and Takeuchi (1995) regard the conversion of and interaction between *tacit* and *explicit* knowledge as the key to organizational knowledge creation. They claim that creating knowledge is not simply a matter of learning from others or acquiring knowledge from the outside. Knowledge has to be built on its own, requiring frequent intensive interaction

[134] Primary and secondary inhibitory loops (See Argyris & Schön, 1996, pp. 89-103).

[135] *Skilled incompetence* refers to the organization's inability to detect and correct because of the Model-I- theory-in-use, that is, the inability is connected to a theory-in-use. Similarly, the existence of skilled incompetence means the unawareness of the inability, and unawareness is also connected to a theory-in-use. Accordingly, it is *skilled unawareness*.

[136] Deuterolearning, implying reflection on inquiry, is closely related to Schön's (1983) concept Reflective Practice. Schön (1983) argues that professional expertise is developed through a lifelong learning process, and that competent practitioners are characterized by their ability for "reflection- in-action" through which they often think about what they are doing while they are doing it. This tacit "knowing-in-action" is developed during practical experience and is a kind of "feeling" that is particularly visible in situations of uncertainty, uniqueness, instability and value conflict. Schön suggests that practitioners elaborate this capability to include reflection on their own practice in order to recognize, surface, and criticize their own strategies of action and their ways of framing problems and roles (i.e. their individual theory-in-use, ref. Argyris and Schön (1996). Such a reflection-on-action stimulates individual and collective learning.

[137] Claiming that organizations may find it difficult to create such learning conditions themselves, Argyris and Schön suggest an OD-program assisted by external facilitators. I find this argument reasonable. On the other hand, I question their use of workshop settings outside the natural organizational context. This is because this approach conflicts with Brown and Duguid's argument that organizational learning and innovation is closely linked to participation in communities of practice. Therefore, it seems more beneficial to base OD- programs on natural organizational settings.

among members of the organization.[138] Therefore, the key to organizational knowledge creation lies in the mobilization and conversion of tacit knowledge where knowledge created by individuals is reinforced through a spiral process moving up through expanding communities of interaction to the inter-organizational level. The underlying dynamic of the *knowledge spiral* is the social interaction between tacit and explicit knowledge bringing about four different modes of knowledge conversion: *Socialization* (from tacit to tacit); *externalization* (from tacit to explicit); *combination* (from explicit to explicit); and *internalization* (from explicit to tacit).

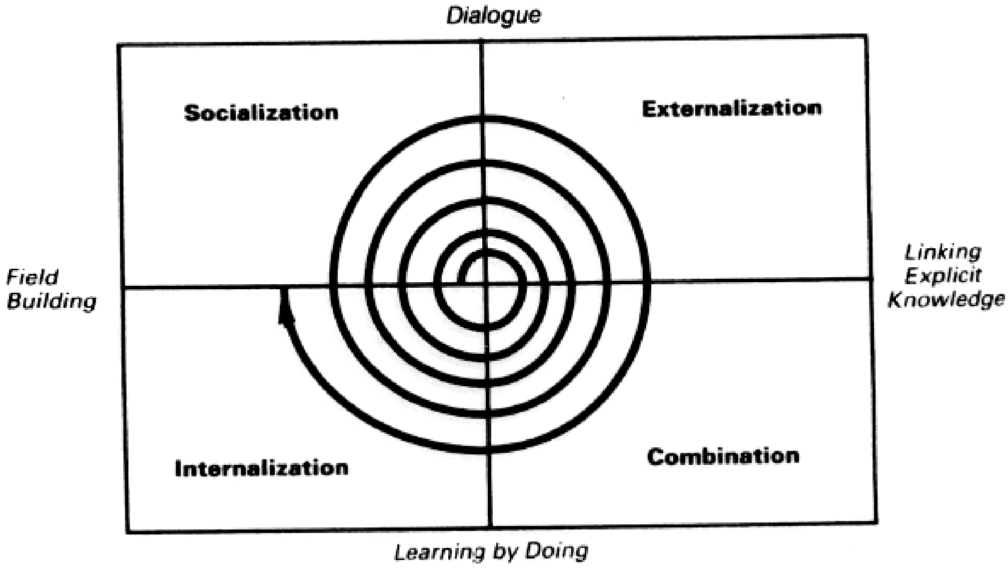

Figure 5.6.2 The Knowledge Spiral (Nonaka and Takeuchi, 1995)

Several triggers induce the different modes. First, socialization often starts with building a "field" of interaction that facilitates for the sharing of members' experiences and mental models. Second, externalization is triggered by meaningful dialogue or collective reflection in which use of appropriate metaphors or analogies helps team members to articulate hidden tacit knowledge that is otherwise hard to communicate. Third, "networking" newly created knowledge and existing knowledge from other sections of the organization triggers combination. Finally, "learning by doing" triggers internalization. Nonaka and Takeuchi emphasize that the core of the organizational knowledge creation process takes place at the *group* level and that the organization must provide the necessary enabling conditions in

[138] A similar argument is given by Brown and Duguid (1991) who claim that organizational learning and innovation is unavoidably linked to individuals' actual ways of working and participating in communities-of-practice.

order to facilitate both group activities and the creation and accumulation of knowledge at the individual level.[139]

Taking the time dimension into account, Nonaka and Takeuchi (1905) propose an ideal integrated, dynamic five-phase model of the organizational knowledge creation process, including 1) Sharing tacit knowledge, 2) Creating concepts, 3) Justifying concepts, 4) Building an archetype, and 5) Cross-leveling knowledge. The process starts with the sharing of tacit sympathized knowledge that corresponds roughly to socialization. Next, tacit knowledge shared by a team is converted to explicit conceptual knowledge in the form of a new concept, i.e. externalization. The created concept has to be justified in the third phase, in which the organization determines if the new concept is truly worthy of pursuit. Receiving the go-a-head, the concept is converted in the fourth phase into an archetype that can take the form of a prototype or an operating mechanism. Finally, the knowledge created in, for example a division, is expanded to others in the division, to other divisions or even to outside constituents such as customers, affiliated companies, universities, and distributors.

5.6.5 Discussion and Formulation of Research Questions

The Temporal Progression of Innovation Processes

Nonaka and Takeuchi (1995) and Van de Ven et al. (1999) provide ambiguous answers to the question of how innovation processes unfold over time. Both groups of researchers emphasize that innovation processes are non-linear processes. Yet, both the MIRP model and Nonaka and Takeuchi's five-phase model display linear characteristics. The MIRP researchers' division of the innovation process into initiation, development and implementation periods is in line with the traditional activity-stage model (Darsø, 2001), focusing on separate, sequential activities such as idea generation, idea development, implementation, and termination. Similarly, Nonaka and Takeuchi (1995) conceptualize the knowledge generation process as a cyclic sequence of knowledge conversion phases. Recalling claims of the unpredictable nature of innovation processes, I question the adequacy of separating the innovation process into clear sequential phases. First of all, I raise a doubt about Nonaka and Takeuchi's conceptualization of knowledge creation as a recurrent predictable sequence of events. The assumption of predictability may give

[139] The enabling conditions are: Intention, autonomy, fluctuation and creative chaos, redundancy, and requisite variety (Ref. Nonaka and Takeuchi, 1995).

innovation managers the mistaken impression that innovation processes are controllable. In fact, the model appears to be a simplified *ideal* model rather than an empirically grounded model taking account of the complexity of knowledge creation processes.[140] Following Engeström (1998), I also question Nonaka and Takeuchi's (1995) assumption that the distinction between tacit and explicit knowledge represents an appropriate basis for discerning phases and recurrent sequential patterns in processes of knowledge creation. The different forms of knowledge may appear in many different orders and combinations in the course of a process of innovative knowledge creation (ibid.).

As opposed to Nonaka and Takeuchi (1995), the MIRP researchers call attention to the unpredictable, uncontrollable nature of innovation processes. At the same time, they divide the process into three distinct sequential phases. This dual emphasis is not necessarily contradictory. For instance, the transition from *initiation* to *development* may first and foremost be intended to mark the transition from unofficial to official innovation activities. Still, the division into apparent clear phases may give the impression that *idea generation*, *idea development*, and *implementation* represent neat phases clearly separated in time. I claim that innovation processes reveal much of the same complex interactions as jazz improvisation. Sawyer's (1992) notion of the complex (simultaneous) interaction of activities and Weick's (1998) attention to the retrospective aspect of improvisation provide strong arguments against the traditional conception of sequential activities. It follows that process models based on the assumption of a split between problem construction and problem solving, or intention and realization are unrealistic (Ref. Engeström, 1998). Accordingly, the MIRP model's attention to three distinct phases represents a great simplification of the innovation process.[141] Equally important, the sequential division between idea generation, idea development, and implementation calls attention to the widespread simplistic understanding of innovation as a linear process in which creativity (in terms of idea generation) *primarily* is linked to the initial period – either representing the first period itself, or having its greatest impact during this stage (Ref. Chapter 4).[142] As

[140] Actually, reading Nonaka and Takeuchi (1995, Chapter 4 Creating Knowledge in Practice), I get the impression that the researchers select examples to fit their ideal model, thereby ignoring the complexity of the knowledge creation process. For instance, when describing the first cycle of the Home Bakery Spiral, they point out that the first prototype produced something that could hardly be described as bread because it had an overcooked crust but was raw inside (p. 102). They call attention to the fact that several problems had to be resolved: The very shape of the dough case, difference in electric cycles, and the temperature. Yet, in their description of the second cycle of the Home Bakery Spiral, the researchers focus on the socialization of kneading skills only. As such, important other problems are left out of the story.

[141] Yet, I consider the model as a fruitful visualization of the innovation journey, not least because of the striking "fireworks" figure.

[142] As discussed in Chapter 4, I argue that it is naïve to consider creativity merely as the starting point of innovation. Certainly, creativity is important in the initial phase of innovation processes. However, my point is that creativity is

such, the MIRP model reflects several erroneous assumptions of the very models the MIRP researchers dissociate themselves with. I argue that innovation require people to continuously define and solve open-ended tasks throughout the complex and unpredictable journey (Ref. Chapters 3 and 4). For this reason, it is necessary to convincingly challenge the sequential (individual) creativity- (collective) innovation model that represents the most prevailing perspectives on creativity in innovation projects. In particular, it is important because conceptualizations of innovation and creativity direct the practical organization and management of innovation.[143] Managers who regard creativity as an individual capacity required in the beginning of innovation projects only, likely assume that innovation success primarily depend on the ability to identify creative people with creative ideas. Indeed, creative people with novel, appropriate ideas are important for success with innovation. However, my point is that a strong focus on creative people and creative ideas may easily result in an over-emphasis on the early periods of the innovation process to the expense of the overall complexity of innovation projects. Therefore, to develop new knowledge of organizational conditions for innovation, I state that it is about time to test the appropriateness of the sequential creativity-innovation model. I propose the following research question:

Is the need for creativity most prominent in the early period of innovation processes?

To study the adequacy of the sequential creativity-innovation model I find it necessary to highlight the research question in terms of both the common definition of creativity (idea generation) and my broader definition of creativity as the individual and collective capacity to define and solve ended-problems in a novel, appropriate way. I argue that an analysis of how “innovative” ideas emerge and unfold over time would provide useful knowledge of whether the creation of new ideas primarily takes place in the early period in innovation projects. Similarly, I think that an investigation into how people collectively create new knowledge in innovation projects would highlight whether innovation requires people to continuously define and solve open-ended tasks throughout the innovation journey, or just in the beginning of it. Thus, I regard the questions *How do“innovative”ideas emerge and unfold over time?* and *How do people collectively create new knowledge in innovation*

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needed throughout *the entire* innovation process. Creativity is a prerequisite for both definition and solving of open-ended problems and for the creation and implementation of new, appropriate products and processes. Hence, I object to conceptualizations perceiving innovation as a linear process progressing from creativity to apparently non-creative ”hard work”.

[143] Evidently, as we think, so we act.

projects? as proper sub-questions in light of the main research question stated above. I now give a broader account of the relevance of these sub-questions.

Van de Ven et al. (1999) and Nonaka and Takeuchi (1995) provide different answers to the question of how innovation processes start. According to Nonaka and Takeuchi (1995), the knowledge creation process begins with the sharing of tacit knowledge about a relatively clearly defined task, captured by their notion of organizational intention formulated by management (Engeström, 1998). The researchers devote no attention to the preceding process in which management obviously has defined the problem. This assumption of a split between problem construction and problem solving, or intention and realization, is unrealistic and neglects important aspects of politics in collaborative work and innovation learning (ibid.). Nevertheless, it forms the basis for classical project management theories presupposing that ideas exist in advance of projects, and that decisions have already been made regarding goals (Darsø, 2001). On the one hand, Van de Ven et al. (1999) take a similar approach when defining innovation as the development and implementation of an apparent clear "innovative idea". On the other hand, MIRP researchers do call attention to the "pre-project" phase. They emphasize that this period represents a long-term process in which several people and events "set the stage" for innovation. Accordingly, in order to fully understand how innovation processes start, we cannot ignore the period leading up to the decision to launch innovation efforts, nor can we treat the phase as separate from the innovation process. The formative phase of innovation projects is of utmost importance, because it is where the seeds of innovation are sown and cultivated (Darsø, 2001). Ergo, it should be regarded as an integral part of innovation processes, as well as of perspectives and definitions of innovation.

I claim that there is a need for more research on the *initiation* period (Ref. Van de Ven et al., 1999) of innovation processes. This period has largely been overlooked, neglected, or treated as non-existent (Darsø, 2001). According to the MIRP model, the initiation period is the phase in which "innovative ideas" emerge. Yet, apart from indicating that the process involves the interaction of several people and events, Van de Ven et al. (1999) do not elaborate into the process of *how* ideas come into existence. Therefore, the question of how "innovative ideas" emerge triggers my attention: First, how does the initiation process start? Necessity, opportunity, and dissatisfaction are regarded the major preconditions that stimulate people to act (Van de Ven et al., 1999), but is it simple to "track down" the very beginning of innovation processes? Second, what are the characteristics of the initiation process? Does the process reflect the same non-linear systems dynamic as does the innovation journey? Does it display characteristics of knowledge creation (Ref. Nonaka and Takeuchi, 1995)? Third, what are the main activities in the *gestation* period (Ref. Van de Ven et al., 1999)? Is the gestation period about *invention,*[144] the creation of the "innovative idea"? That is, does the gestation period include the phase traditionally associated with creativity, i.e. the idea generation phase (e.g. Holt, 1988; Sundboe, 1998; von Stamm, 2003)? Does the gestation period include idea generation after all? Is it largely a period where people become aware of an idea created by others? Viewing the MIRP model in light of Nonaka and Takeuchi (1995), the gestation period represents the "unknown" phase *preceding* socialization and the subsequent *creation of concepts,* i.e. creation of ''innovative ideas." As such, Nonaka and Takeuchi's model suggests that the gestation period is about the definition of a task or a problem supposed to form the basis for a planned knowledge creation process. Thus, it is relevant to ask: What does the initiation period actually lead up to? An "innovative idea" forming the basis for an innovation project? A clearly defined task/problem whose solution presupposes subsequent generation of "innovative ideas"? In turn, these questions call attention to how the "innovative idea" unfolds from the development period on. According to Van de Ven et al. (1999), initial innovation ideas and activities soon branch into many parallel and interdependent activity paths over time. They argue that this proliferation of activities over time appears to be a pervasive, but little understood characteristic of organizational change and innovation processes. Still, apart from outlining some factors contributing to proliferation, the researchers do not elaborate into the proliferation process. I therefore argue that there is a need for more research on how initial "innovative ideas" unfold over time. In addition, I maintain that this question is relevant in light of my main question *Is the need for creativity most prominent in the early period of innovation projects?* Therefore, I propose the following sub-question:

How do "innovative" ideas emerge and unfold over time?

[144] Van de Ven et al. (1999) define *invention* as the creation of a new idea, thereby separating invention from innovation, which is the development and implementation of the new idea. Accordingly, the gestation period seems to correspond to the *invention* period.

Organizational Learning and Knowledge Creation

Argyris and Schön's (1996) notion of organizational inquiry captures the common denominator of the writings on improvisation, organizational learning, and knowledge creation previously reviewed: Emphasis is on the intertwining of thought and action carried out by individuals in interaction with one another on behalf of the organization to which they belong. At the same time, the writings provide different, complementary approaches to understand learning and knowledge creation in work groups and organizations. The main strengths of Argyris and Schön's (1996) theory are its comprehensiveness, systems approach, and attention to the importance of *learning how to learn* through continuous questioning of current practice. Van de Ven et al. (1999) and the writings on improvisation indicate that the theory is particularly relevant for explaining why innovation processes by their very nature trigger the use of inquiry-inhibiting theories-in-use. On the other hand, Argyris and Schön's theory has several shortcomings. First, it reflects several positivistic assumptions. The researchers' emphasis on an observable change in behavior fails to capture the intentions and personal aspirations of organizational members. Likewise, the governing variables *valid information* and *free and informed choices* of the ideal Model O-II system neglect the interpretative dimension and the non-rational parts of human interaction. Second, Argyris and Schön's strategy for moving towards a productive learning system ignores the importance of work-environmental factors, such as supervisory encouragement and group support (Ref. Chapter 5.4). Third, the empirical basis of the theory is data derived from interventions based on workshop settings.[145] As such, Argyris and Schön do not shed light on how people learn and create new knowledge in real-life settings.

In contrast to Argyris and Schön (1996), Nonaka and Takeuchi (1995) call attention to organizational knowledge creation in practice. The main strength of "The Knowledge-Creating Company" is its demonstration of the limits of Western epistemological tradition. The message that we have to recognize the importance of tacit knowledge and transcend traditional dichotomies is important. The writings on improvisation give strong support to this thinking. Moreover, the researchers' attempt to make a comprehensive theory of organizational knowledge creation is praiseworthy. Yet, as previously suggested, their theory suffers from several shortcomings. In sum, the weak points mentioned so far indicate that Nonaka and Takeuchi first and foremost provide ideal descriptions, not

[145] Their theory on Model O-I-learning systems is an empirically grounded model. On the other hand, the Model-O-II-learning system is a theoretical model. It represents an ideal state that hardly exists in real-life.

theories explaining how organizational knowledge creation happens in real-life. I thus question the models' applicability as an analytic tool. Another weakness is the inconsistency concerning individual and collective knowledge creation. On the one hand, Nonaka and Takeuchi regard "organizational" knowledge creation as a social co-generative learning process. They emphasize the central role of teams and compare organizational knowledge creation to a rugby game.[146] On the other hand, the researchers treat the "social" knowledge creation process solely as an instrument for processing individual knowledge; the knowledge conversions are "the mechanisms by which individual knowledge gets articulated and "amplified" into and throughout the organization" (Nonaka and Takeuchi, 1995, p. 57).[147] Hence, it is not clear what Nonaka and Takeuchi really mean when speaking of the "transformation" of individual knowledge into organizational knowledge. I therefore conclude that there is a need for research highlighting the collective dimension of knowledge creation.

Writings on improvisation in jazz and drama underscore that improvisation first and foremost is a *social* phenomenon: The players are in continuous dialogue and exchange with each other, highly dependent on one another to create successful performances. Thus, in order for improvisation to work, the players must be able to play well *together*. They must have high levels of empathic competence including listening skills, supportive "comping" skills, and an "accepting" attitude. By emphasizing this point, the works on improvisation form a significant supplement to Nonaka and Takeuchi (1995) and Argyris and Schön (1996) who neglect the significance of interpersonal skills.[148] Moreover, viewing the writings on improvisation in light of Argyris and Schön, it becomes evident that successful improvisation is not possible within Model-O-I-learning systems. However, where Argyris and Schön argue in favor of a new learning system governed by ”valid information”, ”free and informed choice”, and ”internal commitment”, the improvisation perspective points out the importance of ”process awareness”, ”accept”, ”support”, and

[146] For instance, Nonaka and Takeuchi (1995) argue that human knowledge is created and expanded through social interaction between tacit and explicit knowledge. On page 61 they write: "It should be noted that this conversion is a "social" process *between* individuals and not confined *within* an individual". On the other hand, on page 225 they seem to take an individualistic approach when arguing that "this interaction between tacit and explicit knowledge is performed by an individual, not by the organization itself."

[147] As examples of how an individual's knowledge is transformed into organizational knowledge valuable to the organizational as a whole, the researchers mention "a brilliant researcher's insight leading to a new patent or a shop-floor worker's long years of experience resulting in a new process innovation." (Nonaka and Takeuchi, 1995, p. 13)

[148] At the same time, Barrett (1998) emphasizes that successful team improvisation presupposes highly competent individual players. No amount of empathic competence can enhance a performance it the performer is not up to the task. Thus, successful improvisation requires highly competent individuals who manage to play well together.

”play”. I regard the improvisation imperatives as a better alternative than the Model-II-variables; they represent a sound corrective to the emphasis on control and fear of failure. In addition, the principles are inherent in the art of improvisation, nurtured and practiced by players in jazz and drama. In contrast, the Model-II-variables are rational-cognitive ideal principles ignoring the importance of mutual support and trust. Yet, I do not believe that jazz bands or drama groups always play in accordance with the jazz imperatives; the imperatives are guiding principles subject to continuous practice. Nor do I assume that competence and power is equally distributed among the players. My point is that the “improvisation writers” underscore the close relationship between the players’ capacity to surrender control and ”tune into” one another and the quality of improvisation performances. However, the brief outline of improvisation literature shows that there is need for more empirical research on how people collectively play together to create new knowledge in complex, unpredictable, uncontrollable situations. In this connection, I also maintain that expatiating on this question is relevant in light of my main question of whether the need for creativity is most prominent in the early period of innovation processes. Accordingly, I propose the following question:

How do people collectively create new knowledge in innovation projects?

The Political Dimension of Innovation Processes

The process models reviewed appear to be based on the assumption that innovation processes proceed, or ideally should proceed, in harmonious unison. As such, they represent a limited, naive understanding of power and interests in organizations. For instance, by deriving the phases of the cycle of knowledge creation from modes of knowledge representation, Nonaka and Takeuchi neglect the issue of problem construction, i.e. questioning, debate, and analysis of the problem (Engeström, 1998). These tasks are tacitly delegated to management as an unexamined “black box.” Likewise, Nonaka and Takeuchi’s assumption that the cycle begins with the sharing of tacit knowledge about a relatively clearly defined task, implies an unrealistic split between problem construction and problem solving, or intention and realization (ibid.). No matter how clear the intention or assignment may be for management, the task will be creatively reconstructed by those supposed to solve the problem. If we ignore this point, the important dimension of power will be artificially separated from collaborative work and innovative learning in work organizations and teams.

Furthermore, Nonaka and Takeuchi (1995) and Argyris and Schön (1996) seem to regard political and other self-interested activities as abnormal or dysfunctional features that should be absent in a healthy organization. Indeed, the researchers recognize different interests as a creative force. On the other hand, they seem to think that conflicting interests can and should be solved, creating conditions for oneness and harmony throughout the organization.[149] As a consequence, the researchers neglect the uneven formal and informal distribution of power in organizations (Pinch & Bijker, 1987; Latour, 1987; Clegg, 1989). Organizations are not integrated rational enterprises pursuing a common goal. An organization embraces several rationalities, as rationality is always interest-based. Taking account of the governing variables of Argyris and Schön's O-II-learning system, it is thus necessary to ask: Valid information for whom? Free and informed choices for whom? Whose openness is being pursued? Whose interests are being served? Who benefits? My point is that rationality is always political. Moreover, organizations are made up of *coalitions*, meaning coalition building is an important dimension of almost all organizations. Coalition development offers a strategy for advancing one's interests in an organization (Latour, 1987). Ergo, since organizations are systems of simultaneous competition and collaboration, conflict will always be present in organizations (Morgan,1986).

[149] For instance, Senge (1990) makes a clear distinction between the political win/lose game of *discussion* and the apparently non-political *dialogue* focused on the "free and creative" exploration of complex and subtle issues, a deep "listening" to one another and suspending one's own views. Obviously, Senges' approach is influenced by Argyris & Schön's *O I –and O II learning systems*, where the latter is governed by "valid information", "informed choice" and "internal commitment" (Argyris and Schön, 1996). Similarly, Senge's ideal team learning system is a "non political climate" where the team members share a common vision and see each other as "colleagues" who "speak" openly and "honestly" about important issues (Senge, 1990). Furthermore, in contrast to Argyris and Schön (1996), Nonaka and Takeuchi (1995) argue that double-loop learning is not a special, difficult task but a daily activity built into the knowledge-creating organization. Their main argument is that Argyris and Schön's emphasis on the requirement of an OD-program reflects a positivistic view of organization, assuming that someone outside or inside the organization "objectively" know the right time and method for putting double- loop learning into practice. From their point of view, the capacity for double-loop learning is built into the knowledge creation organization without the unrealistic assumption of the existence of a "right" answer. On the other hand, I question Nonaka and Takeuchi's (1995) assumption that organizations easily performing high-quality inquiries represent an ideal "harmony view". Based on findings obtained worldwide from nearly 6000 individuals of both sexes, ranging widely in majority or minority status, education, wealth, and organizational rank, Argyris and Schön (1996) conclude that close to 99 percent of the people they studied use Model I theory-in-use in threatening or embarrassing situations. Apparently, members of the Japanese organizations Nonaka and Takeuchi studied are not part of the 99 percent referred to by Argyris and Schön (1996). Do they represent the exclusive 1 percent of people that are not programmed with Model-I-theory-in-use, thereby having a natural talent for Model II-theories in use, or do the Japanese learning theorists ignore a major aspect which may have a great impact on the effectiveness on the knowledge spiral? According to them, the Japanese ideal of life is to exist among others harmoniously as a collective self. As such, Nonaka and Takeuchi's notion of Japanese human relationships as collective and organic strongly supports the "natural talent" approach. On the other hand, I still argue that Nonaka and Takeuchi neglect important aspects of the power dimension, as previously referred to.

Summing up, I argue that the process perspectives, in particular Argyris & Schön (1996) and Nonaka & Takuechi (1995), have a distinctly Utopian flavor. The aspects of interests, power and conflict cannot be "unlearned" or learned "away" from organizations or social interactions in general. Power is a natural and ever-present part of organizational life, not a dysfunctional and optional extra (Clegg, 1989). Organizational knowledge creation is a continuous construction and resolution of tensions or contradictions between, among other things, the perspectives of the participants in a complex system. Thus, the political dimension of innovation processes should not be ignored.[150]

Overview of Research Questions

In sum, I propose three related research questions concerning the *process* facet of innovation and creativity. I define two of the questions as sub-questions offering a proper basis for answering the main question. The research questions are:

Research Questions in Terms of the Process Facet of Innovation and Creativity:

Is the need for creativity most prominent in the early period of innovation processes?

How do "innovative" ideas emerge and unfold over time?
How do people collectively create new knowledge in innovation projects?

[150] I shed light on the political dimension of innovation processes in Chapters 5.7 and 12.

5.7 The Partnership Facet of Innovation and Creativity

5.7.1 Introduction

In this chapter I highlight the *Partnership* facet of innovation and creativity, that is, characteristics of innovation as a social, collective achievement.

As is evident from Chapters 2 through 4, I view innovation as a collective, open-ended activity requiring both individual and collective creativity. Innovation is a complex activity in which each individual is part of a larger ensemble of specialists who collaborate to achieve desired ends without a pre-scripted plan and without certainty of outcomes. The specialists depend on each other to define and solve open-ended problems, meaning their ability to play well *together* has a major impact on their overall capability to create and implement novel, appropriate products or processes. It follows that a *Partnership* study of innovation presupposes perspectives pointing up that innovation does not only rely on the accomplishments of single experts but also on the *interaction* between these. This requirement naturally brings the *systems* and *network* concepts into focus.

Both "system" and "network" refer to a combination of components and links and thereby attention to wholes rather than parts. For instance, a system is defined as "*a group of interrelated, interacting, or interdependent entities forming a complex whole*"[151], as "*a set of interrelated or interacting elements, real or abstract, forming an integrated whole*"[152], or as "*a set of interrelated components working toward a common objective*"[153]. Similarly, a network is defined as "*a large number of people, groups, institutions, etc. that have a connection with each other and work together as a system*"[154], as "*a complex, interconnected group or system*", or as "*a system of lines or channels that cross or interconnect*".[155] The network definitions just outlined indicate that a network is often

[151] www.dictionary.com
[152] www.wikipedia.com
[153] Carlsson et al. (2002)
[154] COLLINS COBUILD Dictionary. English Language
[155] www.dictionary.com

defined as a system. Likewise, systems are often referred to as networks.[156] Thus, similar to the concepts "innovation" and "creativity", "system" and "network" appear as synonyms referring to the same phenomenon. At the same time, researchers seem to think of networks as more temporary and less structured sets of interrelated components than systems. According to Fagerberg (2005), a system, in the normal use of the term, will typically have more "structure" than a network and be of a more enduring character. Similarly, DeBresse and Amesse (2000) suggest that in reference to the concept of system one can consider a network as a loose form of an inorganic and decomposable system.

In the study of the *Partnership* facet I consider both "system" and "network" as powerful concepts assisting my aim of highlighting characteristics of innovation as a social, collective achievement. In the current chapter I make use of the concepts to approach the *Partnership* facet from two (related) angles. First, I apply the systems concept to shed light on innovation as a collective open-ended activity. Second, I apply the network concept as a means for addressing creativity as a collective capacity. I now explain this approach in further detail.

I define a system as a set of interrelated components working toward a common objective.[157] This definition calls attention to salient systems characteristics. First, it points up that a system consists of components and relations between them and that the set of interrelated components should form a coherent whole (Edquist, 2005). The components are complementary, meaning there is more to the system than the sum of its interacting components. If, in a dynamic system, one critical component is lacking, or fails to progress or develop, this may block or slow down the growth of the entire system (Fagerberg, 2005). Second, a system has a function, i.e. it is performing or achieving something. Third, it must be possible to discriminate between the system and the rest of the world, meaning it must be possible to identify the boundaries of the system.

The systems concept appears as a fruitful tool for giving an overall picture of innovation as a collective open-ended activity. In the current chapter I have chosen to present an

[156] For instance, a system may be defined as "a network of structures and channels, as for communication, travel and distribution" or "a network of related computer software, hardware and data transmission devices" (Source: http://dictionary.reference.com downloaded 2005- 05- 28). Also some variants of the systems of innovation approach define systems as networks. Freeman (1987, p.1), cited in Edquist (1997), defines a national system of innovation as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies". Likewise, Carlsson et al. (2002) calls attention to that the technological system framework originally was defined as a network of agents interacting in a specific technology under a particular institutional infrastructure and involved in the generation, diffusion and utilization of technology. Similarly, the term "network" can generally refer to "any interconnected group or system" (http://dictionary.reference.com downloaded 2005-05-28)
[157] Ref. Carlsson et al. (2002).

outline of *one* systems perspective of innovation - the systems of innovation (SI) approach - or to be accurate, the SI approach as presented by Edquist (1997; 2005).

The SI approach, which is relevant for all levels of analysis, is designed to take account of that innovation is a complex process determined not only by the elements of a system, but also by the relations between these. It conveys the idea that firms normally do not innovate in isolation, but in collaboration and interdependence with other organizations. As such, the emphasis on the complex relations between the actors/agents in a system is a salient characteristic of, and consequently an advantage of, the SI approach.

When it comes to the concept of *network*, I define a network as *a complex, interconnected group or system* in line with one of the definitions presented above. By referring to an interconnected group or system in general I take into consideration that networks may include human as well as non-human elements. Moreover, my conceptualization of networks as systems points up that networks and systems, like creativity and innovation, are related phenomena. To be specific, I here think of a network as a formal or informal sub-system of an innovation system that embodies the participants' overall capacity to achieve the purpose served by the system.[158] The reasoning behind this idea is this:[159]

The main *function* of an innovation system is to pursue innovation processes, i.e. to develop, diffuse, and use innovations (Edquist, 2005). Since innovation is a complex, systemic activity, the successful accomplishment of the function naturally presupposes the establishment of networks across disciplinary and organizational borders. Networks are thus inextricably linked to the purpose or function of the system. It follows that the quality of the accomplishments of single network members and the relationship between these influence the total performance of the system. As such, networks reflect system attributes such as robustness, flexibility, ability to generate change, and capacity to respond to changes. Accordingly, networks embody the actors' collective capacity to serve the purpose of the system, that is, to innovate. For this reason, I consider the network concept as an appropriate tool assisting my aim of giving a general idea of creativity as a collective *capacity*.

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[158] This idea is inspired by Gelsing's (1992) notion of industrial networks as a description of sub-systems of national and international systems of innovation. The idea also suggests that an innovation system may include several sub-systems in the form of networks.

[159] The following line of argumentation is inspired by the description of system attributes given by Carlsson et al. (2002). The authors argue that the main features of the system are the capabilities of the actors to generate, diffuse and utilize technologies that have economic value (the function of an innovation system).

In the following literature review I have chosen to outline two basically different network approaches that enable a study of creativity at the collective level. First, I outline a few contributions that shed light on the configuration, nature, and content of various types of inter-organizational partnerships. Then I make a brief presentation of Latour (1987). I consider this particular work within the field of actor-network theory as a proper conceptual framework for the study of the political dimension of collective creativity. Latour's *Science in Action* also complements the first group of network approaches by calling attention to heterogeneous networks consisting of both people and artifacts.

To summarize, in the coming literature review I shed light on the *Partnership* facet from two (related) angles. I first shed light on *innovation as a collective open-ended activity* through a brief review of Edquist's (1997; 2005) presentation of the systems of innovation (SI) approach. Then I address *creativity as a collective capacity* by means of contributions highlighting various types of inter-organizational networks and by giving a brief outline of Latour (1987).

5.7.2 The Systems of Innovation (SI) Approach

Systems of innovation can be defined in a variety of ways: supranational, national, regional, sectoral, or technological (Carlsson et al., 2002; Edquist, 1997). Despite their different emphases, the various perspectives hold important similarities which allow them to be clustered as variants of a more general and broadly encompassing systems of innovation approach (Edquist, 1997; 2005). In the current chapter focus is on the generic "systems of innovation approach".[160]

Main Terms

The systems of innovation (SI) approach is designed to take account of that innovation are extremely complex processes influenced by many interrelated factors (Edquist, 1997). It tries to encompass all important factors shaping and influencing innovation which together may be called a "systems of innovation". As such, a *system of innovation may be defined as the determinants of innovation processes*, i.e. all the important economic, social, political, organizational, institutional, and other factors influencing the development, diffusion, and use of innovations (Edquist, 2005).

[160] According to Edquist (2005), his contribution focuses mainly on national systems of innovation. At the same time, he emphasizes that much of the discussion in the chapter is relevant for the generic approach. For instance, when it comes to his presentation of the strengths of the SI approach he explicitly refers to these as strengths of the generic SI approach.

The constituents of systems of innovations (SIs) are *components* and the *relationships* among components.

Components are the operating parts of a system. There is general agreement that the main components in SIs are *organizations* and *institutions*. *Organizations* are formal structures that are consciously created and have an explicit purpose. Some important organizations in SIs are firms, universities, venture capital organizations, and public agencies responsible for innovation policy, competition policy or drug regulation. Institutions are sets of common habits, norms, and routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups, and organizations. Examples of important institutions in SIs are patent laws, health regulations, and technical standards. So, to summarize, organizations are the players of the system, whereas institutions are the rules of the game.[161]

Relationships are the links between components. The properties and behavior of each component of the set influence the properties and behavior of the set as a whole. At the same time each component depends on the properties and behavior of at least one other component in the set (ibid.).[162]

Thus, both the systems components and the relationships between these are determinants of innovation processes.

Furthermore, an SI has a *function*, meaning it is performing or achieving something. The main function in SIs is to pursue innovation processes, i.e. to develop, diffuse, and use innovations (Edquist, 2005). Activities in SIs are those factors that influence the development, diffusion, and use of innovations. As such, they are the determinants of the main function. Examples of activities are R&D as a means of developing economically

[161] The specific set-ups of organizations and institutions may vary among systems. SIs may differ from one another in many different respects. For instance, when it comes to national systems of innovation, the set-ups of organizations and institutions vary among them. Research institutes and company-based research departments may be important R&D performers in one country, while research universities may play a similar role in another. Besides, institutions, such as laws, rules, and norms, also differ considerably among national SIs. For instance, patent laws differ between countries. In the US, an inventor can publish before patenting, whereas this is not possible according to European laws (Edquist, 2005).
[162] Because of this interdependence, the components cannot be divided into independent subsets. Feedback makes systems dynamic. The greater the interaction among the components in a system, the more dynamic it is.

relevant knowledge that can provide a basis for innovations, or the financing of commercialization of such knowledge, i.e. its transformation into innovations (ibid.).[163]

Below, I outline a few institutions, organizations, and activities that I consider relevant in light of my empirical data.

A Brief Outline of Some Institutions, Organizations, and Activities in SIs

Van de Ven et al. (1999) discuss the industrial infrastructure that facilitates and constrains innovation. Among the factors mentioned, I here focus on the following: 1) Institutional arrangements to legitimize, regulate, and standardize a new technology, and 2) Public-resource endowments of basic scientific knowledge, financing mechanisms, and a pool of competent labor.

A variety of *governmental regulations and institutional arrangements* facilitate and inhibit the emergence of new technologies and industries. The patent system grants the patent holder monopolistic rights to use knowledge for a limited period. *Trust*, or customer certainty about product quality, is fundamental to the efficient operation of the market institution. Under conditions of high-quality uncertainty, inferior products often drive high-quality products out of the market because of the bad reputation they create for other industry products. Creating trust represents a particularly significant entry barrier for product innovations that are costly and technologically sophisticated, and whose purchase entails irreversible health or welfare cases for customers. Guarantees, licensing practices, industry regulations, and endorsements by other trusted institutions are among the mechanisms established to counteract this barrier. Firms collectively create and maintain these institutional legitimizing devices through industry councils, technical committees, trade associations, etc. These industry associations, in turn, approach, educate, and

[163] There is no consensus as to which functions or activities should be included in systems or innovations, and Edquist (2005) argue that this provides abundant opportunities for further research. He considers the following activities to be important in most SIs: 1) Providing R&D, creating new knowledge, primarily in engineering, medicine and the natural sciences. 2) Competence building (Providing education and training, creation of human capital, production and reproduction of skills, individual learning) in the labor force to be used in innovation and R&D activities. 3) Formation of new product markets. 4) Articulation of quality requirements emanating from the demand side with regard to new products. 5) Creating and changing organizations needed for the development of new fields of innovation. 6) Networking through markets and other mechanisms including interactive learning between different organizations (potentially) involved in the innovation process. This implies integrating new knowledge elements developed in different spheres of the SI and coming from the outside with elements already available in the innovating firms.7) Creating and changing institutions – e.g. tax laws, environment and safety regulations, R&D investment routines, etc.- that influence innovating organizations and innovation processes by providing incentives or obstacles to innovation. 8) Incubating activities, e.g. providing access to facilities, administrative support, etc. for new innovative efforts. 9) Financing innovation processes and other activities that can facilitate commercialization of knowledge and its adoption. 10) Providing consultancy services of relevance for innovation processes, e.g. technology transfer, commercial information and legal advice.

negotiate with other institutions and governmental bodies to obtain endorsements and develop regulatory procedures. One specific manifestation of industry legitimization is setting technical standards pertaining to component specifications, processes, and performance criteria that new technology designs are expected to achieve.

Basic scientific or technological research provides the foundation of knowledge that underlies technological innovation and makes the commercial births of most industries possible. When it comes to *financing mechanisms*, public institutions tend to play the major role in financing the development of basic scientific or technological knowledge. In contrast, venture capital tends to be the key financial source supporting private firms in transforming basic knowledge into proprietary and commercial applications. In addition, the commercialization of many technological innovations requires unique industry-wide financing arrangements. Few biomedical innovations would be commercially viable without the health care insurance industry and the creation of third-party reimbursement systems. Without such a financial infrastructure for a broad array of biomedical and health care innovations, most patients would not be able to pay for many biomedical devices and treatments.

Strengths and Weaknesses of the Generic SI Approach

Edquist (2005) points out six characteristics often considered to be the strength of the SI.

First, the SI approach places *innovation and learning processes in focus*. As such, it represents a fruitful contrast to conventional neoclassical analysis where technological change is treated as an exogenous factor (emerging outside the economic system), meaning this approach cannot provide a proper understanding of the causal connections between technological change and economic growth (Edquist, 1997). Second, the SI approach adopts a *holistic and interdisciplinary perspective*. The approach is holistic in the sense that it aims to encompass a wide array-or all-the important determinants of innovation. In this way, it contrasts previous reductionist approaches to innovation that *a priori* exclude potentially important determinants (Edquist, 1997).[164] The SI approach also allows for the inclusion not only of economic factors influencing innovation, but also of institutional,

[164] Edquist (1997) refers to the traditional OECD approach as an example of such a "reductionist" perspective. He argues that the traditional OECD approach to technical change and innovation has strongly influenced the kind of data collected on R&D and technical change and that it focuses mainly on the R&D system in a narrow sense. In contrast, the SI approach goes beyond R&D because it, among other things, takes account of that technologies are also developed outside the formal R&D system through for example learning by doing, learning by using, and learning by interacting. In addition, technologies are not only developed, but also produced, diffused and used. They are also changed during these processes. All these additional factors are included in a SI, thereby providing a better understanding of innovation processes than the narrower "reductionist" OECD approach.

organizational, social, and political factors. In this sense it is also an interdisciplinary approach. Third, the SI approach employs historical and evolutionary perspectives that make the notion of *optimality irrelevant*. Processes of innovation develop over time and involve the influence of many factors and feedback processes. Therefore, an optimal or ideal system of innovation cannot be specified. Fourth, the SI approach emphasizes *interdependence and non-linearity*. It points up that innovation processes do not follow a linear path from basic research to applied research and further to the development and implementation of new processes and products. Instead, the SI approach takes into account that innovation is characterized by complicated feedback mechanisms and interactive relations involving science, technology, learning, production, policy, and demands. Accordingly, the SI approach has the potential to transcend the linear view of technical change (Edquist, 1997). Fifth, the SI approach is well suited to a *comprehensive perspective*, as all categories of innovation can be analyzed within it. Finally, the SI approach emphasizes the role of *institutions*, rather than disregarding them. This is important, since institutions strongly influence innovation processes, constituting constraints and/or incentives for innovation (Edquist, 1997; 2005).

Along with the strengths just referred to, the SI approach is also associated with weaknesses in the form of conceptual diffuseness and methodological and analytical challenges. The term ”institutions” is used in several different senses in the literature (Edquist, 2005).[165] Sometimes “institutions” is used to refer to organizational actors as well as to institutional rules. Sometimes the word means different kinds of organizations and players. At other times, the term means laws, rules, routines, and other rules of the game. In addition, there is no consensus as to which functions or activities should be included in a system of innovation. The originators of the SI approach did not address the activities in (national) SIs in a systematic way, and therefore failed to provide clear guidance as to what should be included in a system of innovation. Nor have the boundaries of the systems in terms of activities been defined in an operational way since then (ibid).

With respect to the status of the SI approach, Edquist points up that it is not a formal theory, in the sense of providing specific propositions regarding causal relations among variables. This is because empirical work aimed at studying such relationships is scant. For this reason, Edquist argues that “systems of innovations” should be labeled as an approach or a conceptual framework rather than as a theory.

[165] Following Edquist (2005), I define institutions in the latter way.

According to Edquist (2005), scholars disagree on the seriousness of the weaknesses to the SI approach and how they should be addressed. Some speak in favor of not making the approach too rigorous ("overtheorized"), whereas others argue that it is "undertheorized". The latter spokesmen assert that conceptual clarity should be increased, and that the SI approach should be made more theory-like. Edquist advocates the latter position, arguing that increased rigor and specificity would make the SI approach a better basis for generating hypotheses about relations between specific variables within SIs. In turn, this would enable empirical knowledge that could serve as the basis for further empirical generalizations to develop the framework. More specifically, Edquist argues that a stronger focus on functions and activities would be an important step towards developing a more well-defined SI approach.

5.7.3 Networks

Any network basically consists of nodes and relationships (Gelsing, 1992). In this thesis I define a network as a complex, interconnected group or system that may include human as well as non-human elements (Ref. Chapter 5.7.1). I think of a network as a formal or informal sub-system of an innovation system that embodies the participants' overall capacity to achieve the purpose served by the system. As such, I consider the following brief literature review as a means of highlighting *creativity as a collective capacity*.

A Brief Outline of Categories of Networks

Various forms of inter-organizational partnerships have grown considerably in importance over recent decades (Powell and Grodal, 2005). Heterogeneity in the portfolio of collaborators allows firms to learn from a wide stock of knowledge, and collaboration may allow for a division of innovative labor that makes it possible for firms to accomplish goals they cannot pursue alone. Recent empirical research underlines the importance of networks, showing how inter-organizational relationships lead to various benefits with respect to information diffusion, resource sharing, access to specialized assets, and inter-organizational learning (Powell and Grodal, 2005). Thus, inter-organizational networks in terms of multiple collaborative relationships are a means by which organizations can pool or exchange resources and jointly develop new ideas and skills.

Researchers call attention to several different, partly overlapping networks of innovators. Carlsson et al. (2002) briefly introduces the configuration and content of three types of networks. These networks, which involve market and non-market interaction in technological systems, are *buyer-supplier interaction*, *problem-solving networks* and *informal networks*. Although there may be considerable overlap between these, it is the problem-solving network that really defines the nature and the boundaries of a technological system. This network comprises the overall group of experts involved, covering problem owners as well as experts turned to for help in solving technological problems within the system (e.g. universities and research institutes). Furthermore, buyer-supplier networks are important in technological systems. The more so, the more technical information is transmitted along with the transactions, and the less so, the more commodity-like the transactions are. Finally, informal, mostly personal, networks established through professional conferences, meetings, publications, etc. are often important channels of information gathering and sharing in technological systems.

DeBresson and Amesse (2000) focus on inter-organizational networks in the sense of innovation business firms working together.[166] They identify many types of networks: *supplier-user networks*, *networks of pioneers and adopters within the same industry*, *regional inter-industrial networks*, *international strategic technological alliances in new technologies*, and *professional inter-organizational networks* that develop and promote a new technology. Compared to other types of systems, these networks are relatively loose, informal, implicit, decomposable, and recombinable systems of interrelationships compared to systems. Apart from mentioning these general systems characteristics, DeBresson and Amesse do not give a further description of the various types of networks.

Gelsing (1992) presents a narrower typology of industrial networks, *the trade network* and *the knowledge network*. The trade network consists of relations between user of traded goods and services, and the flow of information is connected to flows of commodities with a certain price. The knowledge network focuses on the flow of information irrespective of its connection to the flow of goods and includes information exchange between users and producers as well as between competitors.

Powell and Grodal (2005) propose a network typology in which the networks are differentiated with respect to two dimensions, *duration and stability*, and *purposesiveness*. Duration and stability concern the extent of embeddedness, varying from open, episodic, or fluid to recurrent, dense connections among a fairly closed group. Purposiveness, ranging from informal to contractual relations, concerns the question of whether networks are

[166] Thus, DeBresson and Amesse (2000) are not concerned with inter-organizational networks in general, only networks of innovating firms.

forged to accomplish a specific task, or evolve from pre-existing bounds of associations. *The invisible college*, which is a network of researchers who form around a common problem or paradigm, exemplifies informal, highly fluid network that emerge out of shared experience of common interest. The *primordial network* represents an informal, long-term network such as the regional network where spatial propinquity helps sustain a common community. In contrast, *supply chains* and *strategic alliances* are examples of formal networks purposively created to accomplish specific tasks. The *supply chain* illustrates a long-term network typified by involvement in a common project, while *strategic alliances* exemplify formal, short-term networks. The types of networks do not represent essentialist categories but may overlap and interweave with one another.

Actor-Network Theory in Terms of Latour (1987)

Latour (1987) provides a network approach that account for controversies and policy issues in innovation and shed light on the social construction of technology. According to Latour (1987), actors involved in technological projects develop strategies to support their own interests and points of view regarding the new technology. First, actors aim at enrolling actors and actants[167] into their project. These efforts are achieved through *translating* their interests to fit the interests of enrolled actors. In this way, actors manage to build larger alliances. Second, in order to keep interested groups in place, actors build the interests into durable artefacts so that they become obligatory passage-points in every-day practice (ibid.). A traffic light, for example, shows how a machine has ”agency” in the sense that it ”causes” people to stop and go in an orderly way. Thus, Latour (1987) gives a name to the common processes whereby things are endowed with the ability to influence human actions through delegation or representation.

5.7.4 Summary Discussion and Formulation of Research Questions

In Chapters 5.6.2 and 5.6.3 I highlighted the *Partnership* facet of innovation and creativity from two (related) angles. I focused on *innovation as a collective open-ended activity* through a brief review of Edquist’s (1997; 2005) presentation of the systems of innovation (SI) approach. Then I addressed *creativity as a collective capacity* by means of

[167] According to Latour (1987), both people able to talk and things unable to talk have *spokesmen*. *Actants* are ”whoever or whatever is represented.” (p.84)

contributions highlighting a few types of inter-organizational networks and by giving a brief outline of Latour (1987).

I argue that the systems of innovation (SI) approach provides a fruitful conceptual framework for studying characteristics of innovation as a social, collective achievement. First, its conceptualization of innovation as a complex evolutionary process requiring interaction across disciplinary and organizational borders is in line with my definition of innovation as a *collective*, *open-ended* activity.[168] Second, its emphasis on interdependence and non-linearity is consistent with my argument that innovation is a complex non-linear process in which creativity is needed throughout the *entire* innovation process.[169] Third, the notion that an SI has a *function* and that this function is to pursue the development, diffusion, and use of innovations, parallels my understanding of innovation as the *intentional* creation and implementation of innovations.[170] Finally, the conception of SI activities as those factors that influence the development, diffusion, and use of innovations is noteworthy. It suggests that the SI approach provides a tool for giving a general idea of innovation as an *overall activity* composed of inter-related sub-activities performed by different players who collectively constitute the ensemble of specialists needed to serve the main function. By providing a set of concepts that encourage visualization, the SI approach simultaneously makes possible overall illustrations of the set of various sub-activities, the performers of these activities, the institutions influencing the activities, and the relationship between these. As such, the SI approach facilitates innovation studies where the primary unit of analysis is the total innovation activity and main focus is on the systems performance as a whole. Therefore, I consider the SI approach as a proper analytical tool for highlighting innovation as a collective open-ended activity.

Regarding the weaknesses of the SI approach, I follow Edquist (2005), arguing that a clarification of basic concepts such as “institutions” and “organizations” is crucial for empirical studies. In this connection, I also speak in favor of Edquist’s definition of organizations as the *players of the game*, at the distinction from institutions referring to the *rules of the game*.

When it comes to the issue of delineating system boundaries and the absence of clear guidelines, I argue that this lack of specification is not necessarily a weakness. I briefly

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[168] Ref. Chapter 2.2.3
[169] Ref. Chapter 4.2.7
[170] Rather than referring to the long phrase “novel, appropriate products and processes” in accordance with my definition of innovation, I here simply refer to “innovations”.

comment on this issue in order to clarify the assumptions underlying *my* use of the SI approach in this thesis.[171]

Edquist's attention to the lack of specification seems primarily to concern *national* systems of innovation (NSIs).[172] I assume that ambiguity as to which functions or activities should be included in a NSI may be problematic, not least because comparative analyses of NSIs seem to be attractive to policy makers who aim to understand differences among economies' innovative performance (Edquist, 2005). As such, a specification of system boundaries would probably facilitate the use of NSIs for this purpose. However, since neither NSIs nor comparative analyses of such innovation systems are relevant in this thesis I simply end the NSI specific discussion here. Rather I present my main assumption about delineation of system boundaries in general:

I believe that the issue of delineating system boundaries represents an open-ended problem which cannot be dealt with through clear guidelines. There is no unique and valid way of delineating an innovation system (Carlsson et al., 2002). For this reason, I regard the specification of system boundaries as a creative process guided by the purpose of the study. In this connection, the *grounded theory* approach, in which theory follows from data rather than preceding it, appears as an appropriate methodological tool.[173] By means of this approach, the understanding of how system boundaries may be defined, emerge in the form of empirically grounded theories about determinants of innovation.

When it comes to the question of whether the SI approach should be developed into a more formal theory or not, I consider its present pragmatic and flexible character to be a clear advantage in light of the purpose of my study. Thus, as opposed to Edquist (2005), I do not regard its current status as a weakness. Rather, the capacity of the SI approach to serve as a conceptual framework for studying characteristics of innovation as a social, collective achievement attracted my attention to it in the first place. Still, the SI approach, as well as the systems metaphor in general, suffers from shortcomings.

The SI approach aims to account for the complexity of innovation by encompassing all the important determinants of innovation. At the same time, the conceptualization of innovation as a set of interrelated components and the relations between these naturally fails to account for the dynamic emergent nature of innovation. For this reason,

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[171] I define a thorough discussion of this issue as beyond the scope of this chapter since my multiperspective approach to innovation implies that the SI approach is *one* among many perspectives highlighted in this thesis.

[172] When presenting this issue he refers to originators of the "national systems of innovation" such as Lundvall (1992) and Nelson and Rosenberg (1993) and he explicitly refer to "national systems" in the phrase ("*the originators of the SI approach did not indicate what exactly should be included in a "(national) system of innovation*" (Edquist, 2005, p.186).

[173] As will be discussed in Chapter 7, I base my empirical study on the grounded theory approach.

visualizations of innovation systems easily give observers the impression that innovation takes place in a bounded, well-defined and relatively stable system, which is not the case (Ørstavik, 2001; Van de Ven et al., 1999). The dynamics of innovation processes implies that a system of innovation is not static, but evolves with alterations in the content of components, as well as in the relationships among various components (Carlsson et al., 2002). A snapshot of an innovation system at a particular point in time may thus differ substantially from another snapshot of the same system at a different time. Accordingly, a systems analysis of innovation can not give a satisfactory account of the full complexity of innovation. I illustrate this by means of the musical score metaphor.

A score of a piece of music is the written version of it, showing all the notes that must be played or sung by a particular ensemble of musicians over time. The score clearly defines the start and end of the music, the overall progression of the music in the sense of *which* musicians are supposed to play or sing at all times, *what* they are going to play, and *how*. Thus, using the terms of the SI approach, we may say that a full innovation score provides a complete overview of *how* the function of the SI (the innovation music), the players, the sub-activities which also embody the institutional rules (the various instrumental parts), and the relations between these *unfold over time*. As such, a full innovation score is capable of highlighting both characteristics of the innovation process (the *Process* facet) as well as characteristics of innovation as a collective activity (the *Partnership* facet).

Yet, visualizations of innovation in this sense would easily get too complex to manage efficiently. At best, visualizations of SIs represent snapshots of an innovation score at a particular point in time or simplified working scores giving a rough overview of the total collective activity. Nevertheless, I maintain that the SI approach is useful because it enables the study of the *Partnership* facet which is the very purpose here. The *Process* facet is accounted for by means of other perspectives presented in Chapter 5.6.

Following Edquist (2005), I claim that a stronger attention to activities would increase our knowledge of, and capacity for explaining, innovation. However, where Edquist concerns himself with the study of activities as a means for increasing the rigor and specificity of the (national) SI approach, I concern myself with the study of activities *by means of the SI approach* in order to develop a better understanding of characteristics of innovation as a collective, open-ended activity. I believe that a SI analysis of activities in innovation projects would provide useful knowledge of innovation as an overall activity composed of interrelated sub-activities performed by players who collectively constitute the ensemble of specialists involved. In turn, a SI analysis of activities and specialists performing these activities would shed light on the set of interrelated diverse competence needed to serve the main function of an innovation system. Clearly, diversity of competence is a salient characteristic of innovation as a collective, open-ended activity. As such, an SI analysis of activities stands out as a relevant, powerful tool for a sophisticated study of the importance of requisite variety of competence discussed in Chapter 5.4.[174] A SI analysis would form a useful complement to the question of how diversity of competence influences collective creativity (Ref. Chapter 5.4). In particular, this is because it would facilitate a close examination of which types and compositions of competence are needed to match the complexity of an innovation system. As such, it would contribute to a better understanding of organizational conditions for innovation. I thus propose the following research question:

Which types and compositions of competence are important to succeed with innovation?

In order to study this question, I find it appropriate to highlight the activities of actors[175]/organizations in innovation projects and the institutions that influence the performance of these activities.[176] Thus, I propose the following sub questions:

Which activities by which actors/organizations are important to succeed with innovation?

Which institutional rules influence the actors/organizations in carrying out activities in innovation projects?

As previously discussed, I think of a network as a formal or informal sub-system of an innovation system that embodies the participants' overall capacity to achieve the purpose served by the system. In Chapter 5.7.3 I briefly presented two basically different networks approaches that enable a study of creativity at the collective level.

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[174] As discussed in Chapter 5.4, I consider competence as the ability to solve simple and complex practical tasks by using relevant knowledge and skills. That is, competence is directly related to a particular task, and to the level of that task. As such, I think of competence as similar to Amabile's (1983a/b; 1988; 1996) concept of domain-relevant skills (Ref. Chapter 5.3) and as a synonymous with expertise.

[175] I here use "actors" as a collective term referring to the various players taking part in innovation projects, e.g. individuals, teams, and "organizations" (Ref. Edquist (2005)).

[176] I believe that a thorough qualitative systems analysis of activities and institutions would provide a valuable complement to much existing SI research (e.g. works by the Norwegian STEP group such as Wiig (1996); Braadland (2001); Aslesen et al. (2002); Fraas and Pedersen (2002)). My impression is that much SI research presents innovations in the sense of outcome in innovation systems, the actors/organizations involved, the relations among these, and the most important types of links. Still, they seem to focus less on in-depth descriptions on what is going on in innovation systems and how actors actually innovate.

The outline of network typologies gives a brief idea of the configuration, nature, and content of various forms of inter-organizational networks. The literature review shows that network term often reflect essential information about the actors involved and the purpose of the network, for instance *buyer-supplier* networks (Carlsson et al., 2002) and *networks of pioneers and adopters within the same industry* (DeBresson and Amesse, 2000). However, the contributions largely represent cursory descriptions of network categories with no in-depth information of how these partnerships promote innovation. Still, the very attention to networks in light of innovation is important. It supports my argument that the study of networks is a proper means for studying characteristics of innovation as a social, collective achievement.

Furthermore, by providing a set of concepts that encourage visualization, network approaches in general make possible overall illustrations of the actors and relationships between these. As such, network approaches enable a powerful demonstration of the collective dimension of creativity. At the same time, visualizations of inter-organizational partnerships in innovation projects may give the erroneous impression that networks are bounded, well-defined, and relatively stable systems, thereby failing to account for that networks are relatively loose, informal, implicit, decomposable, and recombinable sub-systems (Ref. DeBresson and Amesse, 2000). Thus, similar to visualizations of innovation systems, illustrations of networks by means of nodes and arrows should be considered as rough sketches of the actors involved in specific innovation activities and the relations between these.

The latter statement implicitly calls attention to the question of delineation of networks in focus. I argue that in order to determine who is inside and who is outside a network, attention should be on the activity/activities that tie participants together. Moreover, I maintain that a grounded theory approach appear as a proper means for the development of theories, assisting researchers in defining network boundaries.

Latour's *Science in Action* (1987) complements the other network approaches referred to by conceptualizing networks in terms of dynamic, emergent strategic processes involving human as well as non-human actors. However, pushing matters to extremes, Latour (1987) appears to conceptualize technological innovation as a sole political process, thereby ignoring important aspects of collective learning and knowledge creation. [177] From a

[177] For this reason, the contributions on improvisation and organizational learning and knowledge creation outlined in Chapter 5.5 represent important complementary perspectives for understanding the social construction of knowledge.

cynical point of view, his contribution can also be seen as a manual for manipulating the world in favor of one's own interest (Korsvold, 2002).

Yet, I consider Latour's *Science in Action* as a useful approach for shedding light on creativity as a collective capacity. Latour explicitly refers to innovation as a social, collective achievement and provides a set of concepts that enable an analysis of the political dimension of collective creativity.

When it comes to empirical research on networks, recent empirical research shows that inter-organizational relationships lead to various benefits with respect to information diffusion, resource sharing, access to specialized assets, and inter-organizational learning (Ref. Chapter 5.7.3). However, according to Powell and Grodal (2005), most of the studies focus on formal ties established among organizations, meaning that research on informal inter-organizational relations is scant. Furthermore, this research largely represents a quantitative approach, analyzing the effect of networks on patenting, access to information, and the generation of novel ideas.[178] In contrast, studies of multi-party networks emphasize processual aspects of collaboration, but sometimes neglect measurement of the output from relationships, in particular how the sharing and processing of information among network members can determine the generation of novelty (ibid.). Therefore, Powell and Grodal (2005) ask for more research focusing explicitly on different measures of innovative outputs and for research offering a better understanding of the specific ways in which networks shape innovative outputs.

Following Powell and Grodal (2005), I argue that there is a need for more research elaborating on how networks influence the creation of novelty. To be more specific, I state that there is a need for more knowledge of how networks influence collective creativity. I also speak in favor of qualitative case studies of networks in innovation projects. Such network studies appear fruitful in light of my intention of developing new knowledge on organizational conditions for innovation. Therefore, I propose the following research question:

How do networks influence collective creativity in innovation projects?

To explore this question, I suggest that a study of how and why people use existing personal networks and establish new contacts would be useful. Such a study would provide an overview of important formal and informal networks, their characteristics, and the

[178] In particular, patents are used as a measure of innovative output (Powell and Grodal, 2005).

interaction among members of various networks, thereby providing important information about how networks influence collective creativity. I thus propose the following sub question:

How and why do people use and create networks in innovation projects?

Thus, to summarize, my research questions regarding the *Partnership* facet of innovation and creativity are:

Research questions in terms of the partnership facet of innovation and creativity:

Which types and compositions of competence are important to succeed with innovation?

> *Which activities by which actors/organizations are important to succeed with innovation?*
>
> *Which institutional rules influence the activities of the actors/organizations in carrying out activities in innovation projects?*

How do networks influence collective creativity in innovation projects?

> *How and why do people use and create networks in innovation projects?*

Part II: The Context of Research and Research Methodology

This part of the thesis covers Chapters 6 and 7 and gives an overview of the context of my research and research methodology. Chapter 6 introduces the context of my case studies – the fields of aluminum extrusion, mathematical modeling, and pharmaceutical product development. The purpose is to give readers not familiar with these fields a rough idea of relevant concepts and topics to facilitate the reading of the analyses and discussions in Chapters 8 through 12. Chapter 6 also gives a chronological overview of the four case projects. These are the three PROSMAT Extrusion projects, *Long Die Life for Hard Alloys*, *Modeling of flow in the bearing channel*, and *Empirical Modeling*, and the Omacor™ project. In Chapter 7 I discuss my methodological approach and the trustworthiness of my study.

Chapter 6 The Research Context

6.1 Introduction to PROSMAT Extrusion

Chapters 6.2 to 6.4 give a chronological overview of the project PROSMAT *New Modeling Techniques for the Future Extrusion Technology* ("PROSMAT Extrusion" for short), a part of the five-year research program PROSMAT 2000 for the Norwegian process and materials industry (1996-2000). PROSMAT followed the foregoing EXPOMAT program (1991-1995), and PROSMAT Extrusion represented a continuation of research activities within this program. PROSMAT Extrusion, in which Hydro Aluminium was a major partner, aimed at improving fundamental knowledge of processes involved in aluminum[179] extrusion, i.e. the shaping of aluminum sections by forcing cylindrical billets through a die. The main target was to develop state of the art technology in order to set a new standard for extrusion productivity, profile quality, and corresponding cost efficiency within Hydro Aluminium.[180] A new die concept, die design rules, recommendations for die maintenance, and software tools for predicting optimal speed and die design represent main results of industrial use achieved through the project. The research work, organized in three sub projects, was a collaborative effort between Hydro Aluminium R&D Centers, SINTEF divisions and Norwegian universities. The project had an overall budget of 30,3 million, and was funded by Hydro Aluminium and The Research Council of Norway.[181]

The PROSMAT Extrusion project organization consisted of a manager responsible for the overall project and subproject managers for the respective subprojects. In addition, a steering committee was established with representatives of the clients, i.e. Hydro Aluminium and Hydro Raufoss Automotive, and involved research groups.

[179] The name of the metal has two official spellings, *aluminium* (the British English version/Hydro version) and *aluminum* (The American English version) as a result of the following incident: When Alcoa registered as a company in the US, the secretary making out the documents dropped the second "i" in aluminium. (www.hydro-aluminium.com) As this thesis is written in American English, the "shorter" version is used when referring to the metal itself.
[180] PROSMAT New Modelling Techniques for the Future Extrusion Technology. Project report, 1999
[181] Unless something else is specified, the monetary unit for financial numbers throughout this thesis is Norwegian Kroner (NOK)

6.1.1 Some Facts and Figures about Hydro Aluminium

Hydro Aluminium is part of the Hydro Group. With the acquisition of the German aluminum company VAW, Hydro Aluminium in 2002 became one of three major global aluminum companies with approximately 30,000 employees. Hydro Aluminium has a strong position within production and semi-fabrication in Europe. Hydro sells close to three million metric tons of aluminum annually and is continuously enhancing its position in the manufacture and supply of cast, rolled, and extruded products, largely to the packaging, automotive and building industries. In the field of metal recycling, Hydro Aluminium is a market leader.[182] Hydro Aluminium spends about €100 million per year on R&D, being committed to the entire value chain from raw materials to finished products.

Hydro Aluminium (HA) comprises the following sectors, each consisting of additional business units: *Primary Metal*, *Metal Products*, *Rolled Products*, *Extrusion*, *Automotive,* and *North America*. In this context, *Extrusion* and the business unit *Automotive Structures* are of particular interest, representing the industrial financial contributors and clients of the PROSMAT Extrusion Project.

HA Extrusion is a leading manufacturer of extruded aluminum products for the automotive- and building industries.[183] The sector is primarily focused on the European market, but has some operating units in Brazil, Argentina, and South-Africa as well. In Norway, the sector is represented by extrusion plants at Raufoss, Magnor, and Karmøy, and refineries at Gran, Magnor, Karmøy, Vik, and Holmestrand. Key figures 1997: Gross sales: 10,265 million; Employees: 7,630.[184]

Hydro Automotive Structures (HAST) is a world leader in developing and delivering high tech aluminum-extrusion based sub frames, body structures, and crash management systems, i.e. bumper beams and crash boxes, to the automotive industry.[185] Hydro Automotive as a sector is the European market leader in crash management systems, having a market share of 80 percent for aluminum bumper beams.[186] HAST has manufacturing facilities in Norway, Sweden, Denmark, the UK, France, the United States, and one assembly plant in Germany.[187] The activity at Raufoss includes remelting, an extrusion

[182] www.hydro.com
[183] Norsk Hydro Annual Report 2000
[184] PROSMAT: New Modelling Techniques for the Future Extrusion Technology. Project Report, 1999
[185] 11687 Hydro Media 2000
[186] Hydro Aluminium Annual Report 2002, p. 68
[187] 11687 Hydro Media 2000

plant with three extrusion presses, and a profile refinery. Key figures 1997: Gross sales: 2,246 million, and employees: 2,377.[188]

The project PROSMAT *New Modelling Techniques for the Future Extrusion Technology* (PROSMAT Extrusion) takes us into the worlds of aluminum extrusion and mathematical modeling. More specifically, the three sub projects concern research topics, to which terms such as “profiles”, “dies”, “metal flow”, and “FEM-models” are central concepts. As such, the following chapters require that readers have a rough idea of these concepts. I start with brief introductions of the raw material *aluminum*, the *aluminum extrusion process*, and the resulting *aluminum products.*

6.1.2 Aluminum Extrusion

Aluminum

Aluminum is one of the most widely used commercial metals in the world today.[189] The metal has a range of beneficial properties such as unique formability, low weight, and great strength.[190] Also, aluminum can be recycled, and it thus has a higher potential for contributing to sustainable development than most other materials.[191] As a result, aluminum is highly suitable for a wide range of applications. The main application of aluminum extrusion is in the field of building systems and architectural products, such as window systems, shower cabinets, and furniture. In recent years, the main growth area for aluminum extrusions is in the field of mass produced components and systems for the automotive industry.[192]

There are different groups of aluminum *alloys*, i.e. types of aluminum containing small amounts of other metals, thereby giving the actual alloy unique physical and mechanical properties. For instance, the so-called AA 7000 alloys used in car components and systems, are stronger and thereby harder to shape than the AA 6000 alloys used in the building industries. As will be discussed later, the AA 7000 alloys represented a major challenge in the PROSMAT Extrusion project and was the basis for one of the subprojects.

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[188] PROSMAT: New Modelling Techniques for the Future Extrusion Technology/Company Information, Project Description/Annual Report 1999. It should be noted that the present business unit Hydro Automotive Structures in 1997 was represented by the company Hydro Raufoss Automotive, whose key figures are referred to in this presentation.
[189] http://www.hydro-aluminium.com
[190] http://www.snelsons.co.uk/aluminium_properties.html
[191] Støren (2000)
[192] Støren (2003)

The Process, Equipment, and Products

Aluminum extrusions[193] are made from aluminum cylinders called billets (see Figure 6.1.1).

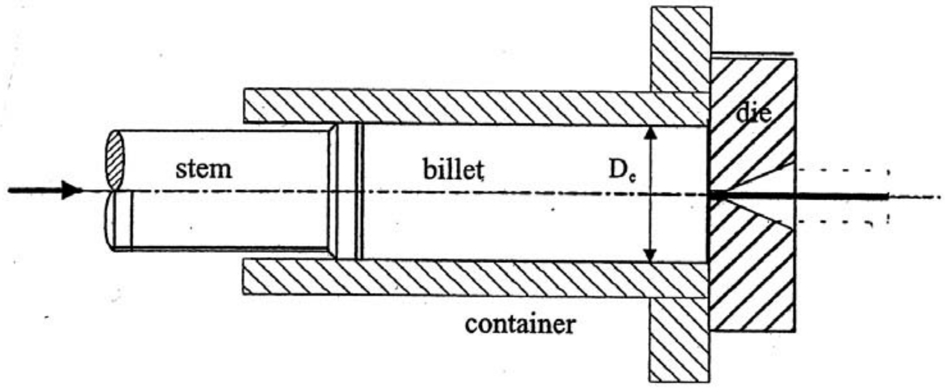

Figure 6.1.1 The Extrusion Process (Source: Støren, 2002)

To make extrusion possible, the billets are usually preheated in an induction furnace to about 450-500°C. The relatively soft billet is then placed in a container and forced through a die opening by a pressing stem, much similar to the process of squeezing toothpaste from a tube. The extruded section leaves the die at a temperature of 500-600°C and is immediately cooled with air or water. The next production step is stretching the section to straighten it and to release internal stresses. The long extruded profile (30-50 meters) is then cut to suitable lengths at a production saw before further processing.[194] Figure 6.1.2 displays extrusions and examples of products made by cutting pieces from extrusions. As seen in the figure, all extruded sections have a fixed cross-section, a result of the constant die geometry throughout the operations.

[193] *Profiles*, *sections, extrudates* and *extrusions* are synonymous terms used in literature on extrusion technology
[194] Sources: http://iprod.auc.dk/mantech/formshap/extru-al/intro/text.htm; Kalpakjian & Schmid (2001); Carlin (2000)

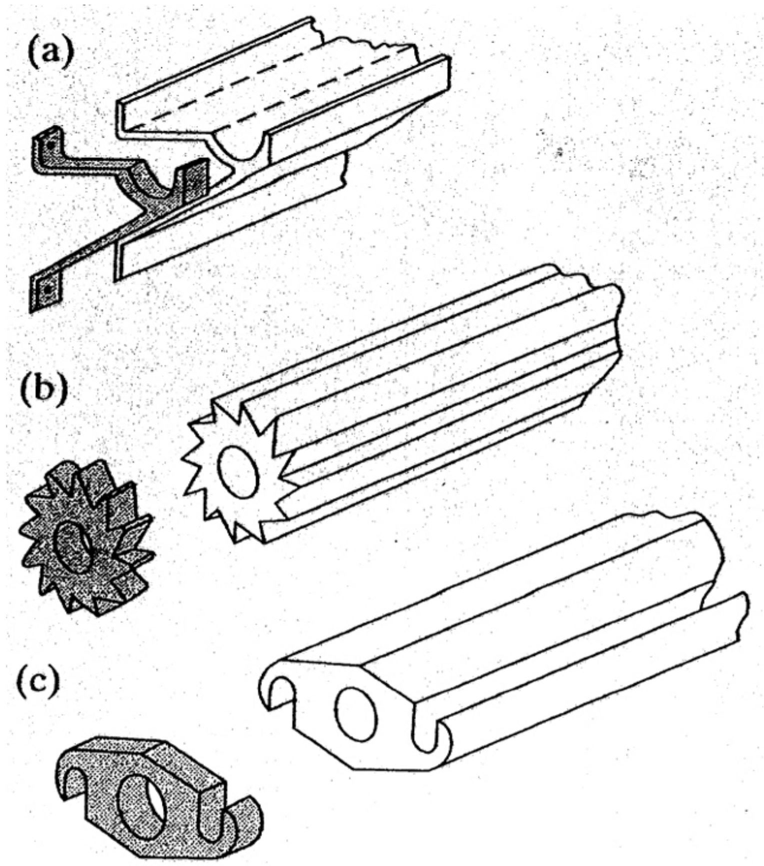

Figure 6.1.2 Examples of products made by cutting pieces from extrusions.
(Source: Kalpakjian & Schmid, 2001)

Generally speaking, there are two main groups of profiles and dies (see Figure 6.1.3). The dies used in extrusion of *open* profiles consist of flat pieces of steel having a die opening corresponding to the actual profile. Hollow profiles, however, requires the use of more complex dies in which the metal is divided into separate streams, flowing around the supports (bridges) for the internal mandrel. These streams are then re-welded in a welding chamber before leaving the die. This process resembles streams of air flowing around a moving car, rejoining downstream.

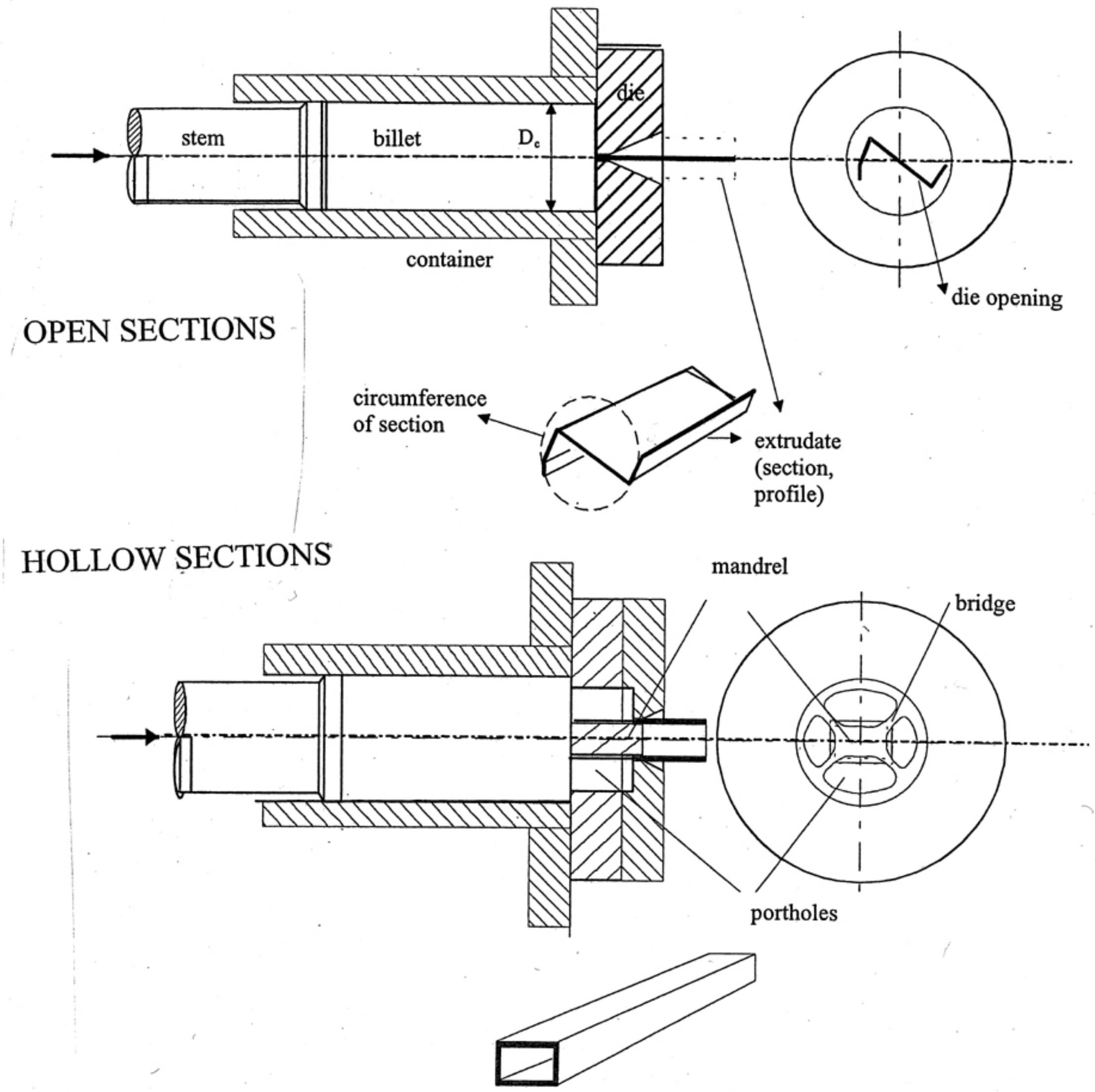

Figure 6.1.3 Open and hollow sections (Source: Sigurd Støren, 2002)

Aluminum Extrusion – A Challenging Process

The process of aluminum extrusion represents a great challenge to both researchers and process operators. First, the forming process itself is very complex. It requires an interdisciplinary research approach from fields such as metallurgy, mathematics, and continuum mechanics. So far, the process is only partly understood. Second, aluminum extrusion is performed in an extreme environment involving high temperatures and pressures. The extrusion pressure is similar to the pressure of 3000 cars parked on a piece of steel the size of a manhole (Figure 6.1.4)[195], meaning the aluminum is exposed to violent changes in temperature and strain rate.[196]

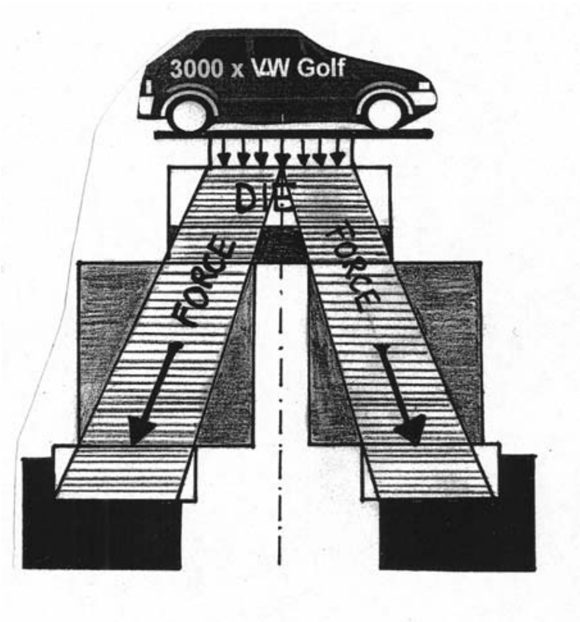

Figure 6.1.4 Illustration of extrusion pressure by means of 3000 VW Golfs (Source: Kindlihagen, 2002)

Thus, extrusion process management is difficult. One of the researchers involved in PROSMAT Extrusion remarked:

> *…Extrusion is not a simple process where you press some metal through [a die] and get a perfect profile as the result. A lot of strange phenomena occur, things you probably had not really expected. The profile does not always get the proper shape, and you enter into problems. You don't manage to do it as fast as you are aiming at …*

In extrusion, thermal conditions are decisive for the quality of the profile.[197] At high temperatures the metal is softer and more fast-running than at lower temperatures. The temperature conditions determine the flow pattern that, in turn, influences the quality and mechanical properties of the final product. Thus, *management of temperature* is the clue to extrusion. Effective management of temperature means that the *extrusion speed* has to be adjusted to fit in with the desired temperature development during extrusion. The maximum obtainable press speed depends on several factors such as alloy type and the complexity of

[195] Kindlihagen (2002)
[196] Skauvik (1994)
[197] The following description of the interaction of geometric and process parameters is a highly simplified, incomplete sketch in which important aspects are left out. It intends to give readers not familiar with extrusion a *rough* idea of the great challenges involved in extrusion process management.

the profile shape. In the words of a SINTEF researcher, the essence of effective extrusion process management may be summarized as follows:

> *…Generally, one wants to use the maximum obtainable extrusion speed for maximum productivity. However, increased speed implies higher temperatures. Besides, the alloy type sets a limit to the maximum acceptable temperature. Lower temperature/speed means a need for increased pressure and a higher consumption of energy. Therefore, the challenge is to optimize all parameters to simultaneously obtain the highest possible productivity, the lowest possible consumption of energy, and the best material properties, surface quality, dimension etc.…*

I now outline some relevant roles, structures and organizational entities in Hydro Aluminium Extrusion. Since the organizational structure may differ between press plants, the organizational structure presented below should be read as an example of a possible structure only.

6.1.3 Some Roles, Structures and Organizational Entities in Hydro Aluminium Extrusion

The dies are produced at *die manufacturing* plants. Hydro Aluminium has four die manufacturing plants in Europe, one of which is located at Karmøy. Sometimes external die manufacturers are engaged as well. Customer requests for new sections are handed over to the *drafting room* (see Figure 6.1.5), where a *profile designe*r makes a draft section shape design of the section.

Based on production limitations and opportunities, a final section design is proposed in close collaboration between the customer, die manufacturer, and extruder.[198] Next, a *die designer* at the die manufacturing plant designs a new die based on his/her experience and feedback from the extruder on earlier designs.[199] An initial version of the die is then produced and tested in the press. *Die correctors* in the *die shop* at the actual press plant make corrections to the die during the test runs until the extruder is satisfied.[200] In general, die correctors are responsible for approving the quality of the die. They prepare and make the dies ready for production and correct and maintain dies that are in production.

198 Carlin (2000)
199 Ibid.
200 Ibid.

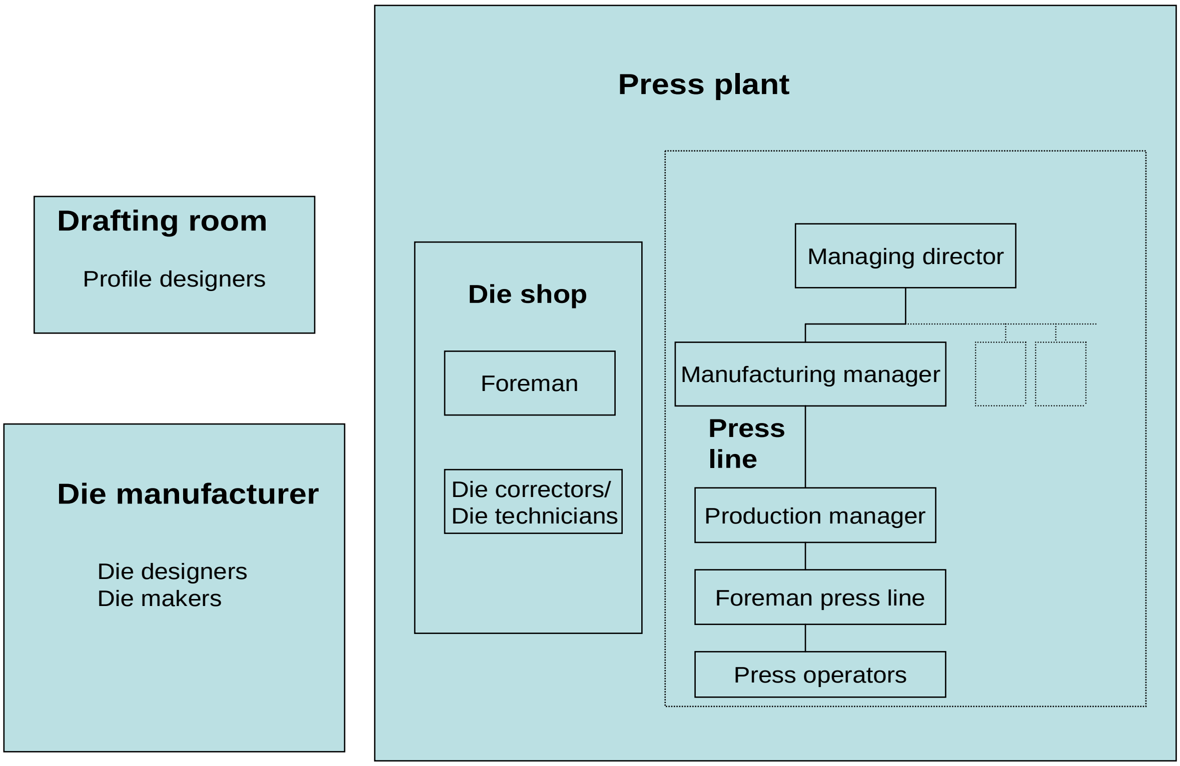

Figure 6.1.5 Roles, Structures and Organizational Entities in HAEX

As seen in Figure 6.1.5, the die shop is part of the press plant headed by a *managing director*. The *manufacturing manager* is in charge of manufacturing issues, while the *production manager* is responsible for the press line, including dies and further processing. The *foreman* at the press line is in charge of the press parameter settings and control of the process at the press line. Finally, the *press operators* take care of the practical "hands on" operation of the extrusion process.

The profile- and die designers, as well as the press operators and die correctors, are craftsmen. As such, the practice of section and die design, the selection and control of process parameters, and the correction and maintenance of dies, are based on the craftsmen's tacit knowledge in terms of personal experience and heuristic rules of thumb.

6.1.4 Mathematical Modeling Techniques

Broadly speaking, the PROSMAT Extrusion projects deal with two main groups of mathematical modeling techniques, the *Finite Element Method* (FEM) and *empirical* modeling. For practical reasons, empirical modeling is presented in Chapter 6.4 in connection with the outline of Subproject 3 *Empirical Modeling*. As such, this chapter focuses on the *FEM* techniques used in Subprojects 1 and 2.

The Role of Mathematical Modeling in the Field of Aluminum Extrusion

Modeling techniques deal with the use of mathematical models and computer simulations to get a better understanding of the mechanisms involved in aluminum extrusion. A simulation is similar to a computer game. As a Hydro researcher explained:

> *…When playing such a game, you may think that you are actually driving a car, seeing people passing by. In our case, you may have a view of the extrusion press. And this program tells us where we get high temperatures, where we get high pressures. And what we direct our efforts at - what we continuously hope to achieve - is the ability to predict the real final shape of the profile…*

Modeling techniques represent an alternative to physical measurements that may be difficult and expensive. For instance, temperature measurement with thermometers is not possible since the thermometers would immediately be ruined by the extreme, adverse environment. Furthermore, simulation provides analysts with far more information than can be obtained from physical tests, providing a better understanding of the extrusion process (Skauvik, 1994). For instance, simulation facilitates *parameter studies*, where the influence of various parameters on the extrusion process may be systematically analyzed. Such studies may form the basis for improvements to the cost and quality of extruded products. Despite the advantages referred to above, the use of mathematical modeling techniques does not make physical experiments superfluous. Verification of modeling results through physical experiments is an essential part of modeling activities.

Simulating the extrusion process is difficult. The process belongs to the group of “worst modeling cases” regarding complexity and difficulty. “It’s not like having a computer program where you provide input data and then receive output data representing the answer under which two lines can be drawn,” a Hydro researcher commented: “ The programs in question are highly complicated. You may imagine a radio with all sorts of buttons that are supposed to be adjusted and tuned in order to receive the best signal. However, there are so many potential buttons to adjust to obtain results. Often emphasis of one aspect will be at the expense of another.” The difficulties are linked to three interacting factors: Finite Element Method computer software, input data on which the simulation is based, and the individual modeler’s competence.

The Finite Element Method (FEM) is a method for solving complex equations, requiring that the object of study is divided into tiny "boxes" called *elements*. Based on this mesh, a FEM-based computer program (*code*) calculates several equations for each element. Simply speaking, this calculation is the computer simulation. There are two main types of FEM techniques, meaning relevant computer codes are based on either one of the two versions. One version is suitable for calculating the strength of solid structures like buildings. The other is fitted for analyses of flow in water or gas, i.e. fluid phenomena. Aluminum extrusion is a composite solid-fluid process, requiring the best part of both variants. However, since no satisfactory combinations are available, and since the development of proper FEM software is both costly and time-consuming, most modelers have to rely on either of the two less proper variants. In turn, this often implies the use of commercial FEM codes developed by international software houses. The fact that the majority of these codes are general standard solutions not adjusted to the particular context of aluminum extrusion, adds further difficulty to the matter.

Furthermore, extrusion process simulation requires reliable input data in terms of process parameter information and *material models* describing the behavior of aluminum under different conditions. However, as physical measurement often is impossible, crucial input data are based on assumptions alone. It follows that the development of reliable simulations of the extrusion process is a complex task requiring the capacity to deal with a composite set of difficulties. The following quotation, which closes this introduction to mathematical modeling, provides a good summary illustration of these challenges:

> *…All the way, mathematical modeling is a kind of craftsmanship. It's not the way a great many people think – that drawing the geometry and having a perfect physical model implies a clear answer. It's far more complicated than that…When you run an economic model, aiming at finding a prognosis for the stock market next month, you put in a number, receiving an answer accompanied by two lines. When we run a simulation, however, we face the situation of comparing two fields expressed in mathematical terms. Of course, you may view it as some colorful graphs. Nevertheless, the interpretation of what these fields actually mean is not trivial. A quick glance at the results is not sufficient to determine whether you've simulated a good design or a good process.* ***You simply have to be an expert to interpret the result at all…You have to be an expert on extrusion and actually have some understanding of both physics and mathematics and to some degree the information technological part of it as well...*** *Thus, the interpretation of results is also a part of the craftsmanship of modeling. You have to have run some models and worked on it a little before you actually understand what the actual result means…*

6.2 Chronological Overview of PROSMAT Extrusion. Subproject 1: Long Die Life for Hard Alloys

This section gives a brief chronological overview of the subproject PROSMAT Extrusion Long Die Life for Hard Alloys. Main activities and major events (indicated by “!”s) are outlined in Figure 6.2.1.[201]

Long Die Life for Hard Alloys was a continuation of research activities in the foregoing EXPOMAT program and in-house Raufoss Automotive projects directed at increasing die life during extrusion of AA7000 alloys, a series of high-strength aluminum alloys. Due to customer demands, Raufoss Automotive had started the production of thin-walled hollow AA7000 profiles in the late 1980s. Extrusion of such profiles led to severe technical problems resulting in “catastrophically” short die life for hollow dies. The die costs were extremely high, resulting in “pure losses”. At the same time, increased competition from the steel industry meant that Raufoss Automotive had to solve the problem in order to survive as a manufacturer of hollow aluminum bumper beams. Through the EXPOMAT period, important results were obtained, contributing to a considerable increase in die life. Still, an additional doubling of lifetime for billets was seen as a prerequisite for competing with bumpers made of high strength steel.[202]

Since one assumed that die life was related to strain in the dies, or more precisely, the occurrence of particular high-stress areas causing cracking (“hot spot stress”), the development of a new die design concept appeared as a main challenge. For this reason, the development of the next generation of extrusion dies for hollow sections in AA7000 became the main project objective.[203]

The five-year project, initially called *Modeling of Strength and Fracture Mechanisms*, was formally started on January 1, 1996, and NOK 12.7 million of the overall budget of NOK 30 million was allocated to the project. The project responsibility was awarded to the Hydro Automotive Research Center at Raufoss. The project manager and a PhD student, engaged from 1999 to 2002, worked full time on the project. In addition, researchers from several SINTEF departments were involved. The involvement of this external competence was regarded as a prerequisite for reaching the long-term objectives of the project.

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[201] The positions of the “!”’s symbolizing major events, are intended to give a rough indication of the point in time for the respective events. Since the events emerge from the combined efforts of several of the listed activity categories, I have chosen to display the events separately.
[202] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Project Proposal. 1995-11-14
[203] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Project Proposal. 1995-11-14

Activity	1996	1997	1998	1999	2000	2001
Pre-project						
FEM strength analysis						
Die Material						
Measurement technology						
PhD study						
Verification/validation						
Major events	! Conclusion: A principally new die design is needed!		! New Die concept: Considerable increase in die life!			

Figure 6.2.1 An Overview of Main Activities and Major Events in PROSMAT Extrusion. Subproject 1: Long Die Life for Hard Alloys.

The project started with a four-month pre-study to find the most appropriate methods and approaches to the problem. Evaluation of methods and results obtained in EXPOMAT and discussions with several relevant research groups and competence persons were in focus. At pre-study meetings several project possibilities were suggested, pointing to FEM stress calculations, better utilization of steel, and practical test methods as main working areas for the project. [204] The research tasks were organized into two subprojects, and the main title of the project became *Strength Analysis and Fracture Mechanisms.*[205]

In 1996 one concluded that the current die design had reached its limit with respect to die life; a further optimization of the design was "theoretically impossible". This conclusion is recognized as an important event of the project, being decisive for its further progress. Investigation into the origin of crack development in dies was proposed as the next step. This was because an understanding of why cracks appear and destroy dies was seen as a prerequisite for creating a new die design.

[204] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Subproject 1: Strength Analysis and Fracture Mechanics. 1996-06-05

[205] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Subproject 1: Strength Analysis and Fracture Mechanics. 1996-06-05

The study of crack development included theoretical calculations and experimental work. Simply spoken, the theoretical calculations included FEM stress analysis examining the relationship between stress levels in die design and geometrical variations.[206] The experimental work included, among other things, mechanical tests to evaluate where, why, and how cracks appeared. For instance, in 1996, fifty dies were investigated after cracking. In addition, several tests were performed at operating temperature to study the connections between stress levels, temperature, and lifetime before fracture. (This work belongs to the "Die Material" category in Figure 6.2) The results from this experimental work provided important input for FEM calculations. Based on theoretical and experimental work combined, prior to 1999, assumptions were made that one was close to a good understanding of crack appearance.

In parallel to, as well as integrated with the efforts just referred to, new die designs were developed and tested in normal production. Several principally new die designs were proposed at a large brainstorming meeting in October 1996. These were investigated during 1997. Moreover, in 1997 it was decided that the new die concepts should not be patented, but registered in an official way due to confidentiality matters. In 1998 the project title was changed to *Long Die Life for Hard Alloys* (hereafter referred to as the "Die Life" project).

Among the concepts tested in 1997, the so-called New Die[207] appeared to be most promising with respect to "hotspot" stress, i.e. the stress level where cracking starts. Optimization of the New Die started in 1998. Simultaneously, investigation of other concepts continued throughout the entire project period. All practical testing in full factory scale was funded through in-house Hydro Raufoss Automotive projects.

During 1998 an optimized version of the New Die was tested in normal production. The performance of the die was, in some cases, considered as highly satisfactory. For several test dies, lifetime before the first crack was much longer than average for the actual profile.[208] The large increase in die life is regarded as a major event in the project. Based on these successful results, ambitions were raised, increasing the original target of die life with more than 60 percent.[209]

Further development of the New Die concept took place in 2000. In particular, the manufacturing of the New Die was given high priority. In 2000, the New Die became the

[206] PROSMAT: New Modeling Techniques. Project Agreement 1997-03-11

[207] The New Die represents a strictly confidential concept. As a consequence, no details concerning the design principles will be given during this case story.

[208] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Project Report 1999.

[209] New Modeling Techniques for the Future Extrusion Technology. Project Report 1999. The specific objectives regarding die life is confidential information.

standard design for most profiles in Hydro Automotive Structures, Raufoss.[210] An internal project was initiated, aiming at further development of the concept. This project has resulted in an improved version of the New Die.

Along with the efforts previously outlined, the development of test methods for direct measurement of stress in hollow dies during extrusion was a main activity in the project.[211] Such test methods, first performed at the SINTEF lab press and then in full factory scale, were seen as a necessity for verification of the numerical simulations. These efforts were delayed, because of severe problems in finding suitable measuring equipment. During 1998 and 1999, however, HAST found manufacturers of equipment that seemed to fulfill the needs concerning measurement techniques at operating conditions, i.e. extreme temperature and pressure. In this connection, a PhD study was started in January 1999, focusing on the development of a particular method for measurement of pressure in dies during extrusion. The resulting “pressure sensor” is seen as a major result of the project, providing unique possibilities for observing the process during aluminum extrusion.[212] The sensor was first tested in the SINTEF lab press, and later in normal production during 2000 and 2001.

The New Die concept, matching die design criteria and manufacturing requirements, and the “pressure sensor” are regarded as the main results of the project. Through the New Die concept, Hydro Automotive Structures managed to reach the new goal regarding die life.[213] The “pressure censor” and measurement technology efforts are seen as successful outcomes of the project, representing pioneering work in the area.

[210] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Final Report, RCN 2000
[211] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Project Agreement. 1997-03-11
[212] 2001 Report RCN HA R&D Materials Technology.
[213] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Project Report 1999; 2000 Report RCN HA R&D Materials technology.

6.3 Chronological Overview PROSMAT Extrusion. Subproject 2: Modeling of Flow in the Bearing Channel

This section presents a brief chronological overview of the second subproject of PROSMAT Extrusion, *Modeling of Flow in the Bearing Channel*. Main activities and major events (indicated by "!"s) are outlined in Figure 6.3.2.

Modeling of Flow in the Bearing Channel started as two separate subprojects, *Modeling of Friction,* and *Modeling of Properties.* Both projects addressed the need for following up on FEM modeling activities initiated during the earlier EXPOMAT program. EXPOMAT projects provided models able to describe the extrusion process *up to* the point where a section leaves the die. Still, difficulties in taking account of *friction* phenomena, i.e. the rubbing of the metal against the surrounding container and die, implied that a satisfactory description of the *bearing channel*, i.e. the surface along which the aluminum flows and is shaped (see Figure 6.3.1), was not available.

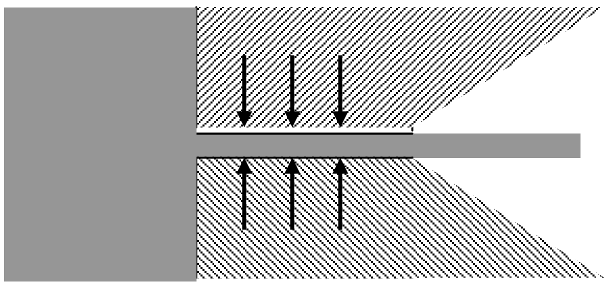

Figure 6.3.1 The Bearing Channel

As a consequence, predictions of a section's movement after the outlet, that is, if it moves straight on or turns away from its original course, could not be made. This problem had to be solved in order to make Hydro capable of meeting the ever-increasing demands for tighter geometrical tolerances (the acceptable degree of variation in shape of the profile), and better surface quality. Therefore, a project directed at friction modeling was proposed as part of PROSMAT Extrusion. *Modeling of friction* was planned as a short-time project serving as the start for further work on geometrical tolerances and surface quality, i.e. themes related to the subproject called *Modeling of Properties*.

Modeling of properties reflected the proposal of bringing tolerances into focus. The theme was motivated by a vision of "zero tolerances". In this connection, comprehensive *global simulations* were seen as a prerequisite for the development of relevant knowledge.

Results from EXPOMAT indicated that studies involving global simulations appeared to be a useful continuation of previous research. So, in sum, the "zero" vision and EXPOMAT research resulted in *Modeling of properties*.

The subprojects were formally started on January 1, 1996. Of the overall budget of NOK 30 million, 9.7 million was allocated to the projects. Project responsibility was awarded to SINTEF Materials Technology in Oslo. Along with the project manager, 8-10 other persons at SINTEF and at the Hydro Aluminium R&D center at Karmøy were involved. A PhD student worked full time on the project in the period from 1997 to 2000. An NTNU postdoc candidate was also engaged, completing his work in 1997. The projects were carried out in close collaboration with in-house Hydro projects such as *Section Surface Excellence* (*SSE*) and *Dies Fit for Use (DFFU)*. The project manager also took part in the *SSE* project. Similarly, several SINTEF researchers were involved in both Hydro projects and PROSMAT Extrusion subprojects.

The subprojects started with a six month pre-study to clarify industrial needs and objectives. The pre-study was also directed at forming the basis for the initial planning and accomplishment of the projects. Project ideas were proposed and evaluated through literature studies and discussions with people at Hydro Aluminium R&D centers, universities, and research institutes.[214] Concerning *Modeling of Friction*, different methods for treating friction in the bearing channel region were evaluated. The so-called Coulomb friction model, well established for metal forming, was chosen. Besides, discussions revealed that a specific surface phenomenon should be taken into account. The development of models for the actual surface phenomenon was seen as important for friction modeling. As such, emphasis expanded from *friction* to *flow*, as reflected in the new project title *Modeling of Flow in the Bearing Channel*. In a similar way, *Modeling of Properties* became *Modeling of Surface Properties* as a result of the pre-project. This was because discussions on industrial needs brought surface quality into focus. Surface appearance was of major importance for the building sector, the largest market for HA.[215]

[214] PROSMAT Extrusion. Modeling of Properties. Pre-study Report. May, 1996.
[215] New Modeling Techniques for the Future Extrusion Technology. Modelling of Properties. Pre-Study Report May, 1996.

Activity	1996	1997	1998	1999	2000
Pre-project					
Friction and special elements					
PhD study					
Study of surface streaks					
Detailed modeling					
Verification					
Major events		! Merger of two subprojects into one		! Successful 2D modeling ! Successful verification	

Figure 6.3.2 An Overview of Main Activities and Major Events in PROSMAT Extrusion. Subproject 2: Modeling of Flow in the Bearing Channel.

Visible defects often meant costly complaints and new deliveries. Therefore, points were made that the development of knowledge on how to avoid surface defects should be given priority.

The projects *Modeling of Flow in the Bearing Channel* and *Modeling of Surface Properties* were run separately throughout 1996. In January 1997 the projects were merged into one sub project, *Modeling of Flow in the Bearing Channel* (hereafter dubbed the "Bearing channel" project), because the activities of the original subprojects were interdependent. For practical reasons, the experimental work and related modeling efforts in the overall project will be presented separately below.

6.3.1 Experimental Die Studies

In 1996 detailed investigations of a large number of industrial samples with surface defects were started, intending to work out a classification system for the various defects on extruded sections.[216] The classification work provided a good starting point for investigations into the causes of various surface defects. More specifically, emphasis was on *interaction* in the bearing channel. This was because most surface defects in extruded sections originated in the interaction between the aluminum and the bearing surfaces. The studies of causal connections between interactions and surface defects represented a major activity throughout the project. The postdoc work involved a large laboratory study of how various extrusion conditions influenced the interaction between the section surface and bearing surface. In addition, another study approached the interaction phenomena by opening up dies with the butt end still inside.[217] This methodological approach is recognized as one of the most innovative aspects of the project.

Until 2000, a large number of dies producing surface defects were closely examined. The experimental work resulted in important knowledge of the causes of surface defects, forming a basis for recommendations on how to avoid such defects.

Verification and validation of the recommendations and hypotheses for surface defects took place during the final two years of the project. A number of extrusion experiments in extrusion plants were done in close collaboration with in-house Hydro projects. In 1999 recommendations on how to avoid surface defects were tested on a few cases “with very good results”. Obtaining these results, referred to as “a great success”, is regarded as a major event in the project.

In 2000, substantial verification was planned in two other press plants.[218] Due to a number of technical problems in both plants, the test series were subject to delays. As a consequence, only a minor part of the test series was actually carried out before the end of the project. Some of these tests did verify the recommendations. Still, the number of dies and billets run for each die was not high enough for making clear conclusions. Therefore, further testing was strongly recommended.

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[216] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Subproject: Modeling of Flow in the Bearing Channel. Final Summary Report. 2000-01-30

[217] The butt end is what is left of the billet in the die when the extrusion cycle is completed.

[218] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Subproject: Modeling of Flow in the Bearing Channel. Final Summary Report. 2000-01-30

The project's final year also involved work on how results from the work on surface defects could be used for improving geometrical tolerances on extruded sections. In fact, recommendations on how to avoid surface defects appeared to have a favorable spin-off effect; they positively influenced geometrical tolerances as well.

6.3.2 The Modeling Efforts[219]

The activity on surface defects formed a basis for the development of numerical models that could predict surface defects, and thus provide descriptions on how to avoid them. Detailed modeling of flow in the bearing channel was contingent upon implementation of models taking account of friction and a specific surface phenomenon. In particular, Coulomb friction in 3D was needed in order to study flow in the bearing channel. However, Coloumb friction did not work in FIDAP, the commercial 3D code used by HAEX. Because of this, the software developers committed themselves to providing Coulomb friction in 3D.

The modeling efforts started in 1996, including a PhD study from 1997 onwards. Among other things, the PhD work aimed at implementing the particular "surface phenomenon" model referred to above.[220] Efforts were also directed at implementing Coulomb friction in the 2D FEM code ALMA developed at SINTEF/NTNU. In late 1997 successful implementation of friction in ALMA was achieved. Other work, on verification in particular, was continued, and completed in 1998.[221] In 1999, the "surface phenomenon" model was successfully implemented in ALMA and coupled with the Coulomb friction.

Based on experience from the 2D work with both FIDAP and ALMA, implementation of 3D Coulomb friction in FIDAP started in 1998.[222] Much delay and testing led to the conclusion that friction in 3D did not work in FIDAP. As a consequence, FIDAP was abandoned as a 3D code for simulation of extrusion, and planned testing in 2000 was cancelled. Five other FEM software codes were explored in 1998.[223] Based on this exploration, the code MARC/AUTOFORGE was chosen.

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[219] The analysis and discussion presented in Chapters 8 through 12 shed light on just a few of the detailed modeling activities and issues presented here. For this reason, the following review should primarily be read as an illustration of the complexity involved.

[220] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Subproject: Modeling of Flow in the Bearing Channel. Final Summary Report. 2000-01-30

[221] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Annual Report 1998 RCN

[222] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Project Report 1999

[223] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Project Report 1999

From the end of 1998 onwards, some 3D simulations with MARC/AUTOFORGE were carried out.[224] These simulations offered a realistic behavior, explaining and demonstrating how local flow imbalances may result in surface defects. Still, they turned out to be very computer power intensive and not yet mature for operational use. In contrast, 2D simulations with MARC/AUTOFORGE turned out to be highly appropriate for operational use. In 1999 detailed 2D simulations of various extrusion cases were completed. A 2D analysis was done in order to compare various strategies for design and corrections of the bearing channel and to study the effect of wear, maintenance, and manufacturing accuracy in the dies. The analysis was verified and validated by comparisons with results from extrusion experiments. The simulations explained known effects of various design and correction strategies. In addition, they contributed to gaining new insight and understanding of how flow in the bearing channel and interactions between the bearing channel and the section surface influence surface quality and geometrical deflections (the amount by which parts of the profile is moved away from their intended positions). These results are recognized as a major event in the project.

All together, activities on numerical simulation and surface properties contributed to increased knowledge and better understanding of mechanisms related to flow in the bearing channel, flow balance, and section surface quality.[225] This new understanding resulted in recommendations for how to avoid surface defects, and guidelines for the design and maintenance of dies.

[224] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Project Report 1999
[225] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Subproject: Modeling of Flow in the Bearing Channel. Final Summary Report. 2000-01-30

6.4 PROSMAT Extrusion. Subproject 3: Empirical Modeling

This section gives a brief chronological overview of the subproject *Empirical Modeling*, part of the PROSMAT Extrusion project. Main activities and major events (indicated by exclamation marks) are outlined in Figure 6.4.1.[226]

Empirical modeling is about modeling the relationships between parameters grounded in analysis and interpretation of empirical data. The *Empirical Modeling* project was based on the idea of utilizing the large amount of process data logged at extrusion presses to predict and optimize process parameters. The five-year project was formally started on January 1, 1996, and of the overall budget of NOK 30 million, 7.6 million was allocated to this sub project. Project responsibility was awarded to SINTEF Electronics and Cybernetics. A project manager and a PhD student, both engaged from 1997 to 2000, worked full-time on the project. In addition, a couple of other researchers were involved during shorter or longer periods during the project.

At the start of the project the approach to be used and the focus of attention to achieve the overall goals were not clear. Therefore, a six month pre-project[227] aiming to investigate viable directions of the main project was initiated.[228] The pre-study resulted in a proposal of five project ideas, of which *Analysis of Production Data and Dependencies on Section Shape* was chosen. This idea included the development of parameters describing section shapes, a tool for statistical analysis and modeling of process and section data, and a tool for searching for similar sections and corresponding process data. Further discussions on direct applications of the ideas concluded with *prediction of press speed for new sections* as the main theme.

[226] The positions of the exclamation marks symbolizing major events are meant to give a very rough indication of the point of time for the respective events.
[227] There are two different "official" versions concerning the duration of the pre-project. According to the pre-study report, SINTEF REPORT No STF 72 F 96 618 1995-12-13 (restricted) New Modelling Techniques for the Future Extrusion Technology Empirical Modelling. Prestudy Report , the pre-project lasted for three months.
In contrast, the final summary report, SINTEF REPORT No STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology Subproject: Empirical Modelling, refers to the "half-year pre-study". Reading this footnote, the subproject manager commented that the pre-project most probably lasted for six months and that he may have written three months in error. Nevertheless, in this context the actual initiation of the pre-project is far more interesting than its actual duration. Furthermore, the date of the prestudy report is 1995-12-13. I assume that the correct date is 1996-12-13 because the PROSMAT Extrusion projects started in 1996. Still, I will keep the date 1995-12-13 in references to the pre-study report
[228] SINTEF report no STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.

Activity	1996	1997	1998	1999	2000	2001
Preproject	! Selection of project idea	! Prediction of speed main theme				
Data collection		! Data analysis triggered initiation of internal project				
Model identification/ Development	! Need for shape analysis recog-nized		! Demo prototypes Speed Predictor and Die Finder			
Methods for shape identification		! Method for analysis of sections shapes from CAD drawings				
PhD study					! Thesis submitted	! Doctoral defense
Master study						
Evaluation Verification/ Validation						
Implementation (Hydro projects)						

Figure 6.4.1 An Overview of Main Activities and Major Events in PROSMAT Extrusion. Subproject 3: Empirical Modeling.

During the first year and a half, process data were collected from three extrusion plants. In parallel, development of software for efficient analysis of process data was initiated. In the early phase it was also made clear that the geometry of sections and dies was an important input to empirical models. In order to do statistical analysis and modeling of process data, project members needed to be able to relate the process data to section shapes.[229] At the same time, the great number of different sections and corresponding CAD[230] drawings necessitated the development of an automatic means of handling these large amounts of data. Consequently, the development of an algorithm for analyzing and interpreting CAD drawings became a central issue. The resulting method for automatic analysis of section shapes from CAD drawings is viewed as a main result of the project.

Early versions of the software for process and shape analysis were ready during the first half of 1997. Results of analyses presented that year revealed large speed variations in the same die at all the extrusion plants. This documentation of operative work is regarded as an event in the project, highlighting the need for further development. Along with an estimated productivity improvement of 10-15 percent by running at consistent speeds, the findings led to the initiation of an internal Hydro project named *Extrusion Process Management.*[231]

The software programs formed the starting point for finding empirical models for predicting press speed. The software development efforts revealed a need for identifying previous sections similar to a new section, and for presenting process data for these sections. The development of relevant software was recognized as a fundamental problem in the project, serving as a basis for a PhD study initiated in 1997.

The software tools named Speed Predictor[232] and Die Finder[233] (later Shape Finder) were developed in parallel. A graduate student was also engaged in these efforts. In the spring of 1998 prototypes were ready for presentation and demonstration at several extrusion plants. The tools were met with great interest and enthusiasm, encouraging the further development of the tools into evaluation versions. The successful realization and demonstration of the initial project idea into these products is regarded as a significant event in the project.

During the fall of 1998 an evaluation prototype of Speed Predictor, including Die Finder as an integrated tool, was installed at two extrusion plants for evaluation of use, benefits of

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[229] SINTEF report no STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.

[230] A plant typically produces several thousand different shapes.

[231] SINTEF report no STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.

[232]Speed Predictor is a software tool that uses empirical models to predict the press speed, productivity, and production costs for new sections based on their shape. Sources: SINTEF Report STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.

[233] Die Finder (later Shape Finder) is a software system searching a database of section shapes for any shapes that are similar to a specific (new) section, displaying key data for these. Sources: SINTEF Report STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.

usage, and performance.[234] In addition, a special version including cost estimation was developed and demonstrated for another plant. Further development of Die Finder into a useful, separate tool was thoroughly discussed. Evaluation of similarity of geometrical features was recognized as a fundamental problem that was given priority throughout 1999.[235]

Throughout 1999 and 2000 (the final year of the project), evaluation and further development of both software tools were main activities, including verification/validation and collection of additional process data. Speed Predictor and Die Finder were evaluated during a six-month period in collaboration with internal improvement projects in two pilot plants.[236] Among other things, both software tools were systematically used in the spin-off project *Extrusion Process Management,* previously referred to. Problems in both plants delayed the evaluation, and a new pilot plant was selected to replace one of these.[237] Die Finder was also used in a feedback system developed in the *Dies Fit for Use* project[238] connected to Subproject 2 (Ref. Chapter 6.3).

In 2000, industrialization of the software tools started in a separate implementation project, aiming at four installations of Speed Predictor in 2000 and ten more in 2001.[239] Shape Finder was installed in the Hydro Extrusion plants integrated with Speed Predictor. In addition, it was installed at die manufacturers.

According to the Final Summary Report, the main results from the project were five different software packages, including among other things, software for the analysis of section shapes and process data, Speed Predictor and Shape Finder.[240] In addition, the Final Summary Report presented a PhD thesis, a Master of Science thesis, nine refereed papers, five technical reports, eleven lectures, and three essays as results of the project. The Speed Predictor and Shape Finder concepts were referred to as "major steps forwards compared to the current state of the art in the industry".[241] Project members regard the development of

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[234] Minutes of meeting 1998-09-08: Steering Committee Meeting 3/98, Vækerøe, 1998-08-26
[235] Minutes of meeting 1998-11- 27: PROSMAT Extrusion : Steering Committee Meeting 4/98, Gardermoen, 1998-11- 27
[236] SINTEF report no STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.
[237] PROSMAT New Modelling Techniques for the Future Extrusion Technology. Project Report, 1999
[238] SINTEF report no STF72 F00624 2000-12-18 New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.
[239] 2000 Report NCR PROSMAT: New Modelling Techniques for the Future Extrusion Technology. 00-01-15 (I assume the actual date of the report is 01- 01- 15 because activities in year 2000 are reviewed); SINTEF Report STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.
[240] SINTEF report no STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.
[241] PROSMAT New Modelling Techniques for the Future Extrusion Technology. Project Report, 1999

Shape Finder as a major academic event, a “world-wide piece of scientific news”. In addition, the PhD thesis where this software tool was developed is seen as a major outcome of the project.

6.5 Introduction to the Omacor™ Project

The Omacor™ project concerns the development of the therapeutic pharmaceutical product Omacor™, a high-concentrate of omega-3 fatty acids derived from fish oil. The product, popularly referred to as “the heart medicine” Omacor™, has shown beneficial effects on a range of risk factors related to cardiovascular disease, which is the main cause of death in the Western world.[242]

6.5.1 Some Facts and Figures about Omacor™ - The First Therapeutic Pharmaceutical to Be Developed in Norway

Omacor™ is a concentrate of omega-3 fatty acids. These fatty acids are so-called essential fatty acids, that is, human beings cannot live without them.[243] Omega-3 fatty acids are constituent parts of all cells in the body and are of special importance for the cardiovascular system.[244] Some of the most important omega-3 fatty acids are found in fatty fish, such as salmon, mackerel and herring.[245]

Omacor™ contains approximately 92 percent omega-3 fatty acids as ethyl esters.[246] 84 percent is a concentrate of EPA and DHA, the two most active omega-3 fatty acids.[247] The quality, safety and efficacy of Omacor™ is well documented and, unlike other omega-3 products, Omacor™ has passed a rigorous testing program to meet international documentation requirements for pharmaceutical products.[248] No serious side effects of the product have been reported.[249] Omacor™ was originally developed at the Hydro Research

[242] Omega-3 magasinet. Informasjon om Omega- 3 fettsyrer, Pronova Biocare a.s, 1994, p. 3
[243] PRONOVA BIOCARE. THE WORLD’S LEADING COMPANY OF OMEGA-3 FATTY ACIDS. Brochure, 1993
[244] Omega-3 magasinet. Informasjon om Omega- 3 fettsyrer, Pronova Biocare a.s, 1994, p. 2
[245] Omega-3 magasinet. Informasjon om Omega- 3 fettsyrer, Pronova Biocare a.s, 1994, p. 2
[246] OMACOR. An introduction. A new edition for a refined treatment. Published by OCC, London 1999, on behalf of Pronova Biocare
[247] PRONOVA BIOCARE. THE WORLD’S LEADING COMPANY OF OMEGA-3 FATTY ACIDS. Brochure, 1993
[248] OMACOR. An introduction. A new edition for a refined treatment. Published by OCC, London 1999, on behalf of Pronova Biocare
[249] KJEMI 03/2001

Center in Porsgrunn and is now the responsibility of Pronova Biocare, a subsidiary of the Norsk Hydro venture company Hydro Pronova AS.[250]

Omacor™ is the first proprietary therapeutic agent ever developed in Norway. The first application for marketing authorization in the EU was considered a milestone in Norwegian Industry.251 While medicinal cod liver oil has a long tradition as an (ill-smelling, ill-tasting) health-bringing part of a healthy diet in Norway and other countries, Norsk Hydro was the first company worldwide to develop fish oil into a patented high-concentrate therapeutic pharmaceutical in large-scale production.

6.5.2 The Dynamics of Pharmaceutical Product Development

The Main Challenges in the Field of Pharmaceuticals

This section serves as an introductory framework for understanding the challenges Norsk Hydro faced when entering the field of pharmaceuticals. It provides an outline of main activities and medicinal terms by referring to the model in Figure 6.5 below.[252]

The model in Figure 6.5.1 frames pharmaceutical product development as the interplay of two main challenges: The “pharmaceutical” challenge (in pink), and the “commercial challenge” (in green). The “pharmaceutical” challenge is the challenge of obtaining *marketing authorization* for a therapeutic pharmaceutical, that is, the license to sell and market the drug to patients and physicians. The “commercial” challenge concerns the efforts of transforming the approved pharmaceutical product into a *commercially* successful product.[253] Here, patents are decisive, because the period of validity of patents represents the period of time for recovering the cumulative investment in developing the therapeutic pharmaceutical (illustrated by the zigzag arrow). The dynamic interactions of the “pharmaceutical” and “commercial” challenges represent the very essence of pharmaceutical product development, as will be outlined next.

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[250] Ferd Equity Fund purchased Pronova Biocare from Norsk Hydro in January 2004. Sources: http://www.pronova.com/filestore/PressRelease22.December2003.doc; “Dagens Næringsliv” 2005-06-17

[251] Profil 5/1993

[252] See Chapter 12 Analysis and Discussion of the Partnership Facet of Innovation and Creativity for a comprehensive discussion of the Omacor™ project in light of the systems of innovation approach.

[253] In the pharmaceutical context, “product” usually refers to an approved pharmaceutical product and its trademark. For instance, the product Omacor™ is the omega-3 high concentrate encapsulated in soft gelatin each capsule containing 1 gram of active ingredient and 4 milligrams of alpha tocopherol (vitamin E) acting as an antioxidant (Source: http://www.pronova.hydro.com/).As such, the substance containing active agents should, strictly speaking, not be regarded as the approved product. Still, for reasons of simplicity, “product” will here refer to both the substance *and* the approved product.

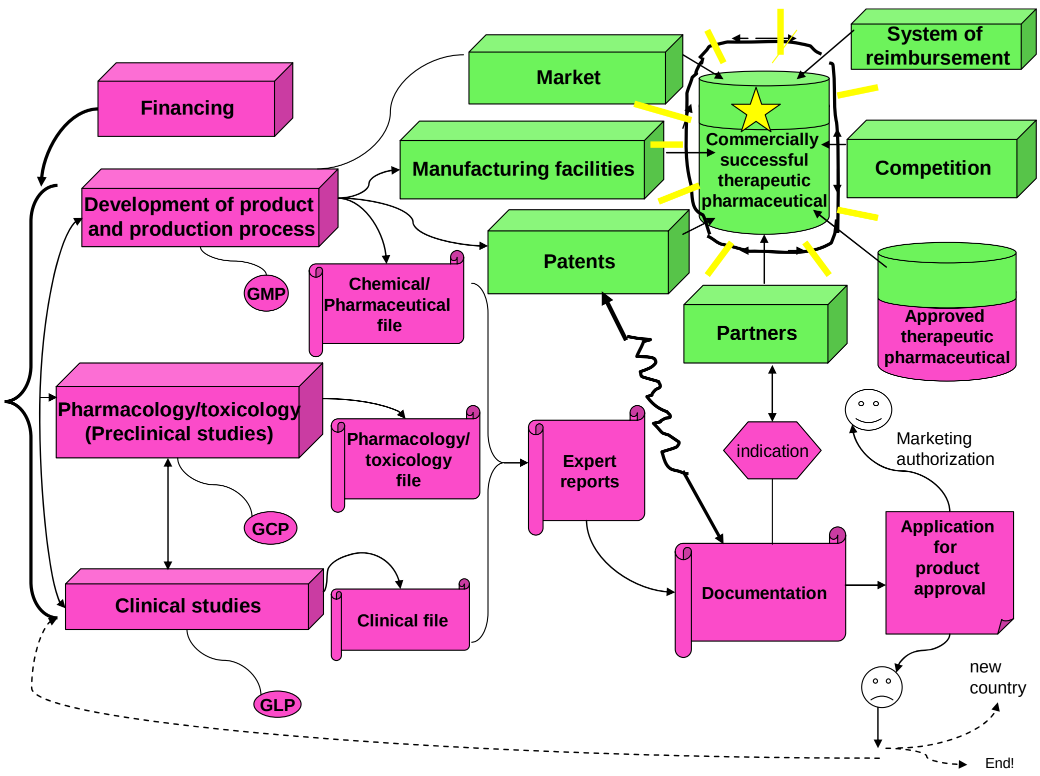

Figure 6.5.1 The Dynamics of Pharmaceutical Product Development

The "Pharmaceutical Challenge"

The challenge of attaining product marketing authorization for a therapeutic pharmaceutical is a time-consuming, expensive comprehensive process. To obtain marketing authorization, the quality, safety, and efficacy of a product has to meet comprehensive documentation requirements for pharmaceutical products. The requirements, which are intended to prevent fraud and protect public health, are defined by national or supranational regulatory authorities such as the Food and Drug Administration (FDA) in the US, and The European Agency for the Evaluation of Medicinal Products (EMEA) in Europe. The requirements apply to three main activities in pharmaceutical product development: *Development of a therapeutic pharmaceutical and a production process*, *pharmacology/toxicology (pre-clinical studies)*, and *clinical studies* (see the left part of Figure 6.5.1).

The *development of a product and a production process* is a great challenge in itself. The process of developing a *therapeutic pharmaceutical* is even more demanding, due to the directions of Good Manufacturing Practice (GMP). The product and production process have to be thoroughly developed, tested and documented in accordance with these rules. The quality of both raw materials and the final substance has to be validated. This implies testing and proving that the actual content of the substance meet required specifications, that is, for instance, that the actual content of the fatty acid EPA in a 50 percent concentrate of EPA is minimum 49 percent, maximum 51 percent, and that the content of impurities is within strict limits. Similarly, the stability of the product has to be tested and documented. Another topic is the validation of analytical procedures. The use of high-quality analytical methods follows from the strict requirements for accurate documentation. GMP requirements also prescribe how to monitor the product and the production process, i.e. how to write protocols and laboratory logs.[254] Thus, the process of obtaining the documentation for the required *chemical-pharmaceutical file* (see Figure 6.5) is comprehensive.

Pre-clinical studies, covering pharmacological and toxicological studies, are studies on animals or cell substances aimed at testing aspects of safety and efficacy of chemical substances. Such studies, which have to be performed in accordance with the directions of Good Laboratory Practice (GLP), are a prerequisite for subsequent studies on human beings. Pre-clinical tests start with smaller, less structured *pharmacological studies* aimed at identifying potential effects of a substance. Then, *toxicological studies* follow, focused on safety topics. The purpose of these tests is to see if the substance has some unexpected, surprising side effects.

Some pharmaceutical companies have their own testing facilities but most companies delegate pre-clinical studies to external specialist laboratories. Similarly, the design of test programs, “protocols,” is either done by in-house biochemical specialists, or by a Contract Research Organization (CRO). Protocols guide the actual performance of studies, specifying the actual number of test animals, the types of tests to be carried out, the dosages of the drug, etc. The protocol designers are responsible for monitoring the tests, i.e. ensuring that they are carefully reported, approving the reports, writing summaries, drawing conclusions, and seeing to the progress of the project. This work forms the basis for the required *pharmacology and toxicology file* (see Figure 6.5).

Pre-clinical studies provide necessary, but not sufficient knowledge on efficacy and safety topics. Early in the process of developing a therapeutic pharmaceutical, the drug’s manufacturer decides what disease(s) the therapeutic pharmaceutical might treat effectively based on the drug’s known effects on the body.[255] The manufacturer then conducts *clinical studies* using people suffering from the disease(s) to determine if the drug is, in fact,

[254] This documentation is also continuously maintained. If the manufacturer wants to change an analytical procedure, to change a specification, have the capsules packed somewhere else, or wants to change the size of the packaging, the manufacturer has to apply for a variation/change.
[255] http://www.medicinenet.com 2006-05-02

effective.[256] In medical terminology, the disease for which a therapeutic pharmaceutical is used is called the *indication*. Therapeutic pharmaceuticals often have more than one indication, which means that there is more than one disease for which it is used.

The term “clinical studies” cover a set of different studies that have to be performed in accordance with Good Clinical Practice (GCP). Phase 1 studies are short-term safety and efficacy studies in healthy humans, providing the basis for subsequent studies on people with the disease(s) or risk factors, so-called Phase 2 studies. These studies involve a small number of human subjects. In contrast, Phase 3 studies are large, long-term studies involving a great number of people. For instance, the GISSI-Prevention Study, representing the “medical breakthrough” of OMACOR™, included 11,324 patients over three and a half years. Clinical studies may also be carried out on approved products. These studies, Phase 4 studies, may focus on particular patient groups, dosages, interactions, etc. Issues related to clinical protocols and monitoring of clinical studies resemble those outlined for pre-clinical studies. Clinical studies are carried out in hospitals or general practices, and the resulting *clinical file* comprises the overall documentation of clinical effects related to the chosen indication.

When the chemical-/pharmaceutical, pharmacology/toxicology, and clinical files are completed, independent experts examine the files. If the experts approve the files, they write expert reports, recommending approval for marketing authorization. The files and expert reports comprise the overall documentation necessary for filing the application for approval (see Figure 6.5.1). If the regulatory authorities determine that there is enough evidence to approve the therapeutic pharmaceutical for the designated indication (treatment of the disease), the indication becomes a labeled indication for the drug.[257] The approval means that the manufacturer is allowed to sell and market the product within the approving country. The manufacturer can claim that the drug is effective for the approved indication and use this information to market their drug to patients and physicians.[258] Manufacturers are not allowed to market their drugs for indications that have not been approved by the regulatory authority.

Since marketing is very important for selling drugs, approval of indications is critical to the financial success of a drug. The decision by the manufacturer to apply for approval for a

[256] The first studies on humans (clinical studies) may start when a sufficient number of toxicological studies have been completed. Then follow more toxicological tests, and subsequent new clinical studies (indicated by the double arrow between the “preclinical” and “clinical” boxes in Figure 6.5.1).
[257] http://www.medicinenet.com 2006-05-02
[258] http://www.medicinenet.com 2006-05-02

particular indication is primarily economic.[259] Manufacturers seek approval for indications that allow the broadest use of the drug in order to maximize its use and the financial return on their investment in developing the drug. For similar reasons, manufactures often apply for approval for several new indications, implying that therapeutic pharmaceuticals may have more than one indication. Usually, applications for product approval are filed in several countries or regions, for instance the EU, thereby expanding the potential for larger markets.

If the application for approval for an indication is rejected, there are three possible further steps: 1) The project may be stopped, 2) Applications related to the current indication may be submitted for approval in other countries, or 3) Applications related to a new indication may be prepared (see the dotted lines in Figure 6.5). The latter path involves further pre-clinical and clinical studies, representing additional costs and time delays.

The "Commercial Challenge"

Obtaining marketing authorization for a therapeutic pharmaceutical product is a necessary, but not sufficient condition for developing a commercially successful pharmaceutical product. The transformation of an approved product into a commercial success, the "commercial challenge", depends on several interacting factors: *Manufacturing facilities, patents, partners,* a governmental *system of reimbursement,* and favorable conditions regarding *market* and *competition*.

Sufficient production capacity is an obvious condition for a commercial manufacturing of a pharmaceutical product. This also holds true for the production of test substances for pre-clinical and clinical studies. Thus, gaining access to satisfactory *manufacturing facilities* is a decisive factor for developers of a therapeutic pharmaceutical product.

Patent rights are necessary, because the period of validity for patents represents the period of time for recovering the cumulative investment in developing a therapeutic pharmaceutical. A product successfully established in the market will face comprehensive competition from so-called generic pharmaceuticals, i.e. copies of the original product, when the period of validity expires. Prices are then often drastically reduced (by up to 30-50 percent). Product patents provide a stronger protection than process patents. A process patent protects the process only, implying that competitors may produce the product using another process. Patents are usually applied for in countries representing potential markets

[259] http://www.medicinenet.com 2006-05-02

for the product, and patent rights are decisive in the matter of establishing cooperation with partners.

Relevant *partners* for developers of an original therapeutic pharmaceutical are pharmaceutical companies that may collaborate in the development process, provide financial support and share the risks during development and/or distribution and marketing of the product. A partnership may also represent a competence network with opportunities for discussing relevant topics related to the challenges of obtaining marketing authorization for a product.

Many medicinal products cost a lot more than potential users are willing or able to pay. Consequently, national social or medical security systems attempt to compensate for this through a third-party system of *reimbursement*. While some countries automatically include new approved drugs in this system, other countries have a restrictive policy due to tighter health budget limits. The new drug is assessed regarding its usefulness and the existing market of similar products. Often, “strict” health authorities argue that the new product is not necessary, referring to a number of other (generic) therapeutic pharmaceuticals for the same indication. When drugs are not part of the reimbursement system, patients have to pay full price for these drugs. In addition, doctors wanting to prescribe the medicine have to refer the patient to a specialist, who in turn has to make a special application for reimbursement for each individual patient. Consequently, reimbursement is a critical factor related to the conditions of market and competition.

Manufacturers of new therapeutic pharmaceuticals have to consider several aspects related to *market* and *competition*, especially when entering a well-established market for a particular disease. The conditions of market and competition interact with all the other factors discussed above related to the development of a commercially successful medicinal product (as shown by rectangular and circular arrows surrounding the “commercially successful therapeutic pharmaceutical” in Figure 6.5.1). For instance, a situation of little or no competition and a correspondingly favorable market potential, is of little value unless the approved product is reimbursed. Similarly, obtaining reimbursement for an approved product is useless if there are no patients to use it. Still, a marketing authorization, reimbursement and a promising market potential *without* patents, will not make a commercial success. However, obtaining a patent is no guarantee for success if the product meets severe competition from products already in the market, or new and better products being introduced. Likewise, even when adding strong competitive power to a beneficial patent situation, the total effect of these beneficial conditions is strongly counteracted if a manufacturer without an in-house marketing department has no partners to help distribute and market the product.

Thus, the development of a commercially successful therapeutic pharmaceutical depends on a system of several interacting factors. The state of separate components and the simultaneous interaction of these components determine the “faith” of the new drug.

6.6 Chronological Overview of the Omacor™ Project

This section gives a brief chronological overview of the Omacor™ project.[260] Main activities, major events, and organizational ownership in the period 1984-2001 are outlined in Figure 6.6.1. I define the year 2001 as the final year of my study.[261]

The origin of the Omacor™ project was a research program on chemical extractions from marine biomass, initiated by Hydro, the Fisheries Research Center and the University of Bergen in the early 1980s. One of the projects aimed at developing a process for extracting enzymes from fish waste. The process was based on fish ensilage, implying storage of fish waste in large silo tanks at specified production parameters. During storage the fish "digested itself", providing a water phase containing enzymes and a fatty by-product on top. The emergence of the problematic fat raised the question of what to do with it. Dumping was no favorable solution, bringing the idea of a commercial utilization into focus. In 1984 contact was made with The Hydro Research Center in Porsgrunn. Among other things, the potential for the development of a therapeutic pharmaceutical based on omega-3 fatty acids was discussed. During the fall of 1984, preliminary research was started at the Research Center to explore the issue in further detail.[262] Corporate Technology staff (T-staff) was responsible for the pre-project.

The research project, entitled "Fine Chemicals from Fish Waste", was formally started on January 1, 1985.[263] The budget for the first year was NOK 400,000.[264]

[260] The phrase "Omacor™ project" is a simplification. The original title of the research project leading up to the patented therapeutic pharmaceutical Omacor™ was "Fine- Chemicals from Fish Waste". This title was later changed to "Omega-3 Concentrates". The project included work on several omega-3 concentrates of which the development of Omacor™ (called *k85*) represented *one* activity only. Thus, the phrase "the Omacor™ project" should, strictly speaking, refer to the specific development of *k85*/Omacor™ alone. Still, I use the phrase "Omacor™ project" as a collective term for the specific work on *k85*/Omacor™ and the overall research on omega-3 concentrates.

[261] Most of my empirical data, covering the period 1984-2001, is information about the research activities conducted at The Hydro Research Center, Porsgrunn. As a consequence, the greater part of this overview describes this work, meaning important issues pertaining to the "commercial challenge" (Ref. Chapter 6.5.2) and Pronova Biocare's area of activity (e.g. clinical studies and marketing authorization) are not accounted for. In addition, I have little information about important recent events, for instance Ferd Equity Fund's acquisition of Pronova Biocare in 2004, and the fact that Omacor™ has become a great commercial success. However, since I finished my data collection for the Omacor™ project in 2001, I have defined this year as the final year of this overview. Some recent information is added in footnotes.

[262] "Finkjemikalier fra fiskeavfall. Vurderinger ved start av prosjekt i Analytisk avdeling". 1984-11-22

[263] "Finkjemikalier fra fiskeavfall. Vurderinger ved start av prosjekt i Analytisk avdeling". 1984-11-22

[264] "Prosjektoppdrag. Nytt oppdrag. Prosjektnavn: Finkjemikalier fra fiskeavfall" 1985-01-29

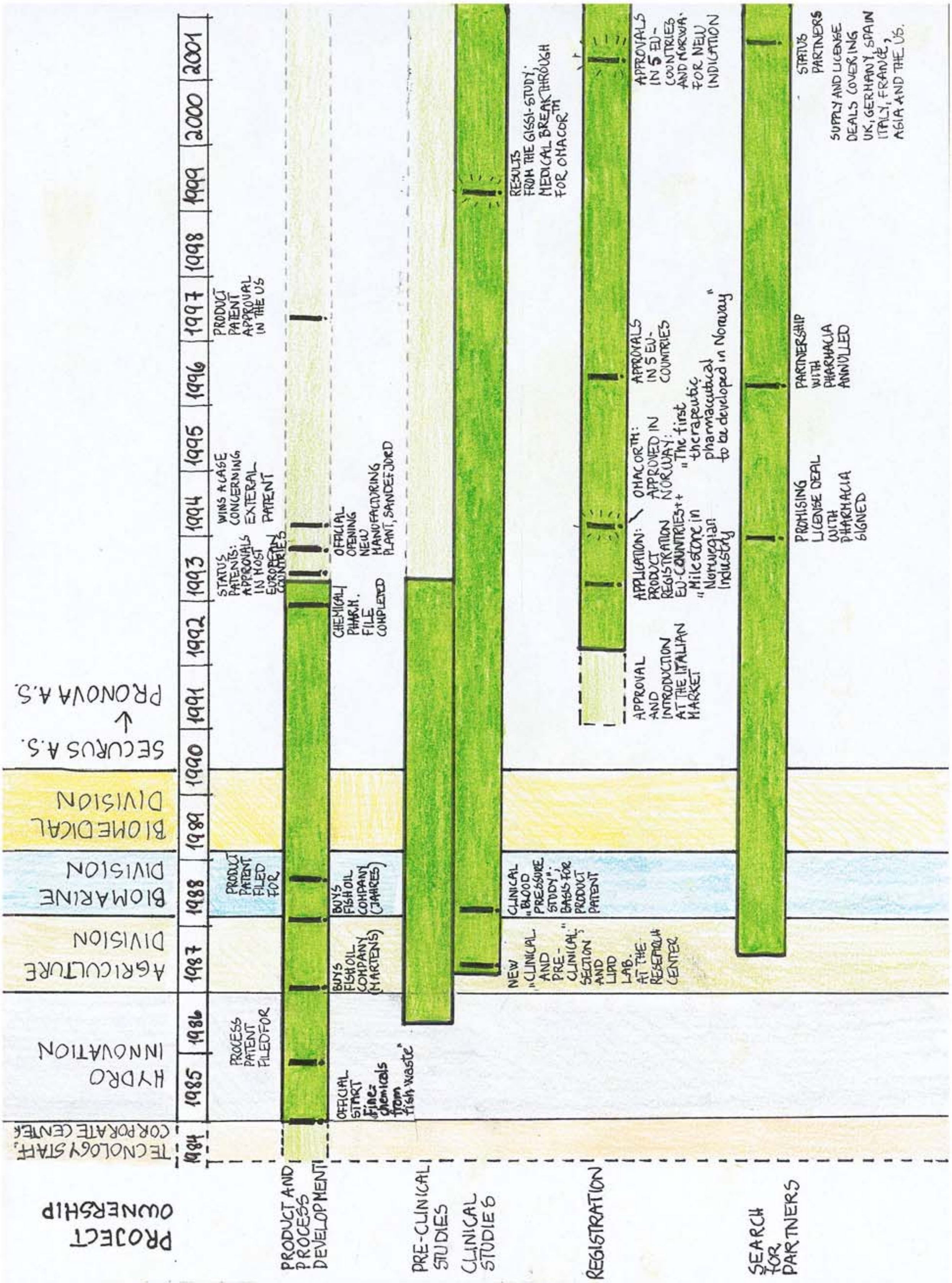

Figure 6.6.1 An Overview of Main Activities, Major Events, and Organizational Ownership in the Period 1984-2001

At that time, the T-staff had been replaced by Hydro Innovation, a new business division responsible for the exploration and development of new business ideas within the areas of biotechnology, materials technology, and offshore.[265] Hydro Innovation thus became the “cradle” of the project. Initially, several fatty components were explored, but the omega-3 fatty acids EPA and DHA appeared to be of greatest interest. As such, a main target became the development of a high-concentrate based on EPA and DHA, a substance that was to be called *k85*. The first patent application was filed at the end of 1985.[266]

The work on developing a large-scale production process started in the winter of 1986, involving several departments at the Norsk Hydro Research Center, Porsgrunn, as well as other organizational units in Norsk Hydro.[267] Key activities were investigating practical process design, searching for potential contract plants, and planning the building of a manufacturing plant. During the summer of 1986 pilot trial production was initiated, providing test material for the first pre-clinical studies which were carried out in the fall of the same year.[268] Efforts were also directed at finding possible application areas for a by-product resulting from the production process.[269] At the end of 1986, Norsk Hydro bought J.C. Martens AS, a Norwegian fish oil company that by chance was up for sale at this time.[270] The responsibility for the project was taken over by The Hydro Agricultural Division, heading, among other things, the marine activities of fish farming and fish food.[271] A year later, in the beginning of 1988, Norsk Hydro acquired their main competitor in the Norwegian fish oil industry, Jahres Fabrikker AS.[272] Both Martens and Jahres produced low-concentrate omega-3 fatty acids as nutrition supplements. As such, the acquisitions provided access to high-quality fish oil, production technology, and competence, making Norsk Hydro one of the leading fish oil companies worldwide. The responsibility for the marine business activities was transferred to the newly established Biomarine division.[273] The project title was changed from “Fine Chemicals from Fish Waste” to “Omega-3 Concentrates.”[274]

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[265] ”Norsk Hydro” 2/86
[266] ”Finkjemikalier fra fiskeavfall. Status ved utgangen av 1985” 1985-12-19; Patentsøknad: ”Raffinert fiskeavfallsprodukt og fremgangsmåte for fremstilling av det samme”. Filed 1985-12-19
[267] ”Produksjon av ω3-konsentrater, EPA og DHA. Status august 1986” 1986-09-02
[268] ”Produksjon av ω3-konsentrater, EPA og DHA. Status august 1986” 1986-09-02; ”Produksjon av ω3-konsentrater, EPA og DHA.” Referat fra prosjektgruppemøte 1986-10-09.
[269] ”Produksjon av ω3-konsentrater, EPA og DHA. Status august 1986” 1986-09-02
[270] Årsberetning 1986 Norsk Hydro
[271] ”Omega3-konsentrater fra fiskeoljer. Status februar 1987”
[272] “PROFIL” 4/1988”; Årsberetning 1988 Norsk Hydro
[273] ”Årsberetning 1987 Norsk Hydro”
[274] “Konsentrater av omega-3 fettsyrer. Status april 1988” 1988-04-27

During 1987 and 1988 large-scale trial production of *k85* was partly contracted out to other producers in Denmark, England, and Germany, providing material for pre- clinical/clinical studies, stability studies, and further process development.[275] Norsk Hydro entered into a cooperation agreement with a British company specializing in encapsulating chemical substances, and the first stability study was initiated in 1987.[276] An important milestone was the initiation of Phase 1 studies in 1987.[277] At the same time, The Norsk Hydro Research Center, Porsgrunn, established a new department for clinical and pre-clinical studies. This department was cooperating closely with hospitals and contract institutions In addition, a lipid laboratory analyzing fatty compounds in blood was established at the Research Center. Work on improving the quality of *k85* continued throughout this time period. The main focus was the development of methods for removing "unwanted" components, thereby increasing the purity of the material. Efforts directed at developing high-quality, international standard analyzing methods were also given high priority.[278] A comprehensive international network including leading research groups in Europe, Canada, and the United States was established as a result of these efforts. Along with promising results from a clinical blood pressure study, several process refinements made the basis for a product patent that was filed in 1988.[279] By 1993 the patent covered most EU-countries.[280] In the US, however, the patent was subject to considerable opposition, being finally approved in 1997. Norsk Hydro also challenged a third party patent due to its obvious similarity. Norsk Hydro finally won the case in 1994.

In 1989 the Biomedical Division was established, replacing the pharmaceutical company Hydro Pharma and the Biomarin Division.[281] At the end of 1989, the project organization consisted of 21 people.[282] The total project investment on documentation and R&D was in the order of NOK 25 million. In 1990 the project and Hydro Pharma became part of Securus AS, a venture unit of Norsk Hydro later named Hydro Pronova AS.[283] The responsibility for pre-clinical and clinical studies was transferred to a new clinical

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[275] "Konsentrater av omega-3 fettsyrer. Status april 1988" 1988-04-27
[276] "Minutes of meeting" 1988- 08- 24 Meeting re. stability studies
[277] Letter to "Statens legemiddelkontroll" re. information about clinical testing of k85 1987-11-02
[278] "Konsentrater av omega-3 fettsyrer. Status april 1988" 1988-04-27
[279] Patent "FATTY ACID COMPOSITIONS CONTAINING OMEGA-3-FATTY ACIDS" Priority number: GB 19880019110 19880811. esp@cenet. European Patent Organization. Downloaded 2005-12 09 from http://www.v3.espacenet.com/textdoc?DB=EPODOC&IDX=NZ230022&F=0
[280] "Forskningsposten" 7/1993
[281] "Norsk Hydro årsberetning 1988".
[282] Svendsen (1996)
[283] PROFIL 4/90

department located in Oslo.[284] The Research Center continued working on the pharmaceutical/chemical file, which was completed by the end of 1992.[285]

In 1993, the first application for product approval in the EU and several other countries was filed, representing a milestone in Norwegian industry.[286] At this time, several studies on other potential indications had been carried out, and *hypertriglyceridaemia*[287] was chosen as the initial indication. The official product name was Omacor™. 1993 was a year of two other major events. In November, a new manufacturing plant for producing omega-3 concentrates was officially opened.[288] It was located at the site of the former Jahres fabrikker. Having modified the production technology of Martens and implemented a new production line at Jahres, Norsk Hydro was able to start commercial production of *k85* in 1991/92. *K85* had obtained a product approval in Italy in 1991.[289] This was followed by a successful market introduction. The new plant provided a threefold increase in production capacity for *k85*, representing new opportunities concerning the international market. Furthermore, immediately before the opening of the new plant, Norsk Hydro signed a cooperation agreement with Pharmacia, the eighth largest pharmaceutical company in Europe.[290] This agreement was considered to be a "very important milestone in the direction of the market"[291], and Pharmacia was licensed to market Omacor™ in most European markets, as well as in New Zealand and Australia. Omacor™ was expected to be on the market within two years (from 1993).[292]

In 1994, Omacor™ was approved in Norway, being the country's first domestically developed therapeutic pharmaceutical.[293] The application in the EU was subject to delays, approvals finally being issued in 1996.[294] Meanwhile, however, the cooperation agreement with Pharmacia had been terminated as a consequence of the merger of Pharmacia and Upjohn. Moreover, Omacor™ had not attained status as a reimbursed therapeutic

[284] Two of the project members working with the Department of Pre-Clincial and Clinical studies at the Norsk Hydro Research Center, Porsgrunn, started a CRO on their own in Telemark in 1991.
[285] Minutes of meeting 1992-10-07. Meeting re chemical/pharmaceutical file
[286] "PROFIL" 5/1993
[287] Simply spoken, *hypertriglyceridaemia* refers to a state of an elevated level of triglycerides (fatty components) in the blood. This state is a risk factor for heart disease. Source: "Omacor™. An introduction. A new edition for a refined treatment". Pronova Bioare a.s., 1999.
[288] PROFIL 22/93
[289] "Norsk Hydro årsberetning 1991". The application for this product registration, being subject to less strict restrictions than the ones previously discussed, was taken care of by a marketing partner.
[290] PROFIL 21/93
[291] Forskningsposten 6/1993
[292] Forskningsposten 6/1993;PROFIL 21/93
[293] "Norsk Hydro årsrapport 1994"
[294] Memo 1996-06-07. "Re: Konkurrenter til Omacor™ og andre omega-3 fettsyreprodukter fra Pronova."

pharmaceutical in Norway. In addition, the Italian market had collapsed due to termination of the national reimbursement system.

In Italy a large clinical study, the so-called GISSI-Prevention Study involving 11324 post-MI[295] ("heart attack") patients, had been initiated, expected to determine the future of Omacor™. The results, published in the prestigious medical journal *The Lancet* in August 1999, demonstrated that treatment with Omacor™ resulted in a 20 percent reduction in deaths and a reduction of more than 40 percent in sudden deaths.[296] This represented a medical breakthrough for Omacor™. Applications for product approval for the secondary prevention of post-MIs were filed, resulting in approvals in Norway and five EU-countries in 2001.[297] Applications for approvals in other countries were still pending approval. The GISSI study and the subsequent product approvals were considered the breakthrough for Omacor™, providing strong, interesting commercial possibilities.

Two separate license and supply agreements were signed in 2001, providing access to new important European markets (UK, Germany, and Spain), in addition to existing agreements covering Italy, France, Norway, Asia, and the US.[298] The forecasts for a commercial breakthrough were regarded as stronger than ever before. Pronova Biocare expected that the cumulative investment, in the order of several hundred million kroner, would be recovered.[299] The market potential for Omacor™ was considered considerable:[300] The US and European markets constituted a target group of approximately 11 million patients, and there was no direct competitor in the market at the time. Based on these promising forecasts, Pronova Biocare with its attractive "heart medicine" was expected to be up for sale within a few years, in accordance with the policy of Hydro's venture unit Hydro Pronova AS.[301]

[295] MI is an abbreviation for myocardial infarction, commonly known as "heart attack". Source: http://www.drkoop.com/ency/93/000195.html downloaded 2005 12 09
[296] OMACOR. An introduction. Pronova Biocare, 1999.
[297] http://www.pronova.com/ (Press release 2001-10- 30)
[298] http://www.pronova.com/ (Press release 2001-12-11)
[299] http://www.pronova.com/ (Press release 2001-12-11)
[300] "Dagens Næringsliv" 2001-12-11
[301] Ferd Equity Fund purchased Pronova Biocare from Hydro in January 2004. http://www.pronova.com/filestore/PressRelease22.December2003.doc. ; "Dagens Næringsliv" 2005 06 17; Omacor™ (as well as the overall omega-3 business) was characterized as a commercial success in the newspaper "Dagens Næringsliv" Friday, June 17, 2005.

Chapter 7 Research Methodology

7.1 Introduction

In this chapter I discuss how I went about studying innovation as a multifaceted phenomenon based on retrospective case studies of the four research projects reviewed in Chapter 6. I start with a brief outline of how the idea of a *multiple-case study* (Yin, 1989), or a *collective case study*, to use Stake's (1995) terminology, emerged in the first place. Next, I present my ontological position to explain why I have based my research process on the *grounded theory* approach (e.g. Strauss and Corbin, 1990; Glaser, 1992) and qualitative case studies (e.g. Yin, 1989, Stake, 1995). After these introductory sections I give a brief overview of my data sources and data collection process followed by a description of how I analyzed and interpreted the data, i.e. my theory building approach. Finally, I discuss the trustworthiness of my study, accounting for the techniques I have used to meet the research criteria applied within the grounded theory approach.

A major point in the current chapter is that my research process has not progressed in a linear fashion in which the development of the theoretical framework was followed by formulation of research questions, data collection, data analysis, and conclusion in a sequential manner. Rather, my inquiry has been an improvisatory process (Ref. Chapter 5.6) characterized by an ongoing interplay of theory building, data collection, data analysis, reading, writing, and reflection – each activity guiding the next step, allowing what was relevant to emerge. As such, neither the structure of this chapter nor the tidy logic of the thesis as a whole reflects how my research process actually unfolded.

7.2 Entering the Field: From "SOIL" to the 1999 Birkeland Award Finalists

In the end of 1999 I was hired as one of the PhD students in the subject area *Knowledge Network* in *The Industry Innovation Fund for NTNU*. We were to study conditions for knowledge creation and innovation in complex organizations. I was to do my empirical study in Norsk Hydro, and the so-called "SOIL" (Secure Oil Information Link) project had been proposed as an interesting case. Nevertheless, getting in touch with those Hydro people appointed as my contacts proved to be difficult. Repeated attempts to make contact were without success. In addition to being overwhelmed by the new impressions and challenges of my “new life” as a researcher rather than musician, I became anxious and impatient: Three months - no “progress,” just ever-increasing frustrations as I attempted to get properly started. Then I made an important decision: I decided to start writing a diary.

Similar to my previous daily warm-up exercises on the horn, writing diary entries every morning became a powerful way of warming up my mind (and calming down my restlessness as well). Similar to practicing and preparing for concerts, thinking on paper became critical for tuning into and practicing the role as a researcher. Writing has been an important part of my work ever since. It has guided my inquiry, continuously reminding me that research is not about prediction, control, and tidy arrangements. Rather, research is about nonstop practice of a rhythmically flexible preparedness for the unexpected (Setreng and Alterhaug, 1987) and faith in the power of emergence.

However, when I started my daily writing sessions in late January 2000, I was first and foremost *worried*. I was particularly anxious about the prospective case work in Hydro, not least because most of my colleagues had got in touch with people in “their” companies “long ago.”

Then, one day my supervisor called me from Oslo. He told me that he had joined a meeting in Norsk Hydro where he had been informed of the newly established *Birkeland Award for Excellent Research in Norsk Hydro*. My supervisor suggested that the five finalist projects could serve as an appropriate basis for a study of innovation in the company. He also mentioned that one of the jury members was an NTNU professor and recommended I get in touch with him to learn more about the projects. I was thrilled at the promising news and immediately called the NTNU professor to make an appointment. We had an interesting and informative conversation about the award and the finalist projects some days later. In the meantime, my supervisor had conversations with the head of the Norsk Hydro R&D corporate group, and he arranged a meeting between the three of us at the end of February. The purpose of the meeting was to discuss relevant research topics in light of the particular needs and interests of Norsk Hydro. The Hydro manager called attention to the traditional emphasis on stepwise process improvements, stating that it would be beneficial for Norsk Hydro if I could study how the company could stage for a larger degree of radical product innovations. My supervisor and I found this to be an interesting idea. As such, the initial attention to the “SOIL” project was dropped in favor of a study of organizational conditions for radical innovation based on retrospective studies of the Birkeland Award finalist projects. Most importantly, though: Eventually I got started!

7.3 My Ontological Position and Methodological Approach

This thesis aims to promote the understanding of innovation as a multifaceted phenomenon. As opposed to research aimed at explanation in terms of cause-effect relationships, my research thus requires a *holistic treatment* of the object of study and a commitment to *interpretation* (Stake, 1995). To gain a better understanding of organizational conditions for innovation, I have to be an interpreter and gatherer of interpretations. I need to search for *happenings* rather than causes, I have to aim at understanding the complex relationship among all that exists, rather than pressing for explanation and control, and I have to emphasize *particularization* and provide “thick descriptions”, “experiential understanding”, and “multiple realities,” rather than focusing on generalization (ibid.).

The aim of understanding versus explanation is epistemologically quite different. My research purpose naturally implies a constructivist position. Accordingly, my ontological position in this thesis is the one of “constructed realities” (Lincoln and Guba, 1985). I assert that it is dubious whether an objectively true reality exists. Rather, I argue that *all* knowledge represents social constructs. Reality is constructed in the minds of individuals and in the social interaction between these in such as way that it becomes a socially constructed reality (Berger and Luckmann, 1966). Since there are numerous individuals, there is also an infinite number of constructed realities, and hence *multiple realities*. None of these realities are exactly similar to one another (ibid.; Osmundsen, 2005). I also recognize that knowledge is mutually constructed in the interaction between the inquirer and the “objects” of inquiry (Lincoln and Guba, 1985; Charmaz, 2000). Thus, objectivity in its pure form is unattainable, meaning truth is determined by group consensus (Lincoln and Guba, 1985; 2000).

Paradigm positions have implications for conducting research. A *grounded theory* approach, in which theory follows from data rather than preceding it, is a necessary consequence of a constructivist stance that posits multiple realities.[302] No a priori theories can anticipate the many realities that the inquirer inevitably will encounter in the field (ibid.).

[302] What grounded theory is and should be, is contested (see for instance Glaser (1992), Seale (1999), and Charmaz (2000). I speak in favor of the *constructivist grounded approach* advocated by Charmaz (2000).

Key characteristics of the grounded theory approach are *inductive qualitative data analysis*, *emergent design*, and *progressive focusing* (Lincoln and Guba, 1985; Strauss and Corbin, 1990; 1998; Glaser, 1992; Seale, 1999; Charmaz, 2000). Essentially, grounded theory methods consist of systematic inductive guidelines for collecting and analyzing data to build theories that explain the collected data (Charmaz, 2000). The methods can be used as flexible strategies to make sense of data. Throughout the research process, grounded theorists develop analytical interpretations of their data to focus further data collection, which they use in turn to inform and refine their developing theoretical analyses. The methods of grounded theory hence include simultaneous analysis and collection of data.

The emphasis on inductive analysis naturally recognizes *emergence* as the foundation of grounded theory building. The researchers approach their inquiry with an open mind and with a minimum of preconceived ideas to allow the research design, research questions, and theories emerge from the data.[303] As the inquiry proceeds, it becomes *progressively focused*. Concepts and relationships emerge, guiding the researcher's further data collection. Insights grow and theories evolve, continuously clarifying the research focus.

Not only is my attention to the grounded theory approach a natural consequence of my ontological position. It is also the most appropriate approach in terms of the nature of my research problem and my initial *theoretical sensitivity* (Strauss and Corbin, 1990; 1998). The study of innovation as a multifaceted phenomenon naturally lends itself to grounded theorizing (and to *qualitative* research, as will be discussed later). In addition, the allowance and recommendation to enter the field with as few preconceived ideas as possible, fit well in with my role as a novice in the field of innovation research and my

[303] Glaser (1992) and Strauss and Corbin (1990; 1998) propose contrasting assertions as to how open-mindedly researchers should approach their inquiry. According to Strauss and Corbin (1900; 1998), the research question in a grounded theory is *a statement that identifies the phenomenon to be studied*. The research question provides the flexibility and freedom to explore a phenomenon in depth. It begins as an open and broad question that gets the researcher started. The initial research question is not so open as to allow for the entire universe of possibilities, yet not so narrow that it excludes discovery, and it becomes progressively focused during the research process. Strauss and Corbin also point out that the research question helps researchers stay focused throughout the research project. Whenever he or she begins to flounder or get lost in the masses of data, the original question can always be returned to for clarification.

As opposed to Strauss and Corbin, Glaser (1992, p. 25) strongly underscores that the research question in a grounded theory is ***not** a statement that identifies the phenomenon to be studied*. He argues that grounded theorists move into an area of interest with *no problem* and keeps his mind open to the true problems in the area, trusting that the problem and questions regarding the problem emerge from the inquiry.

Concerning the divergent positions just outlined, I find it fruitful to consider the initial research question as a conceptual structure (Stake, 1995) to improvise on, helping the researcher to get started. As Charles Mingus insisted, "you can't improvise on nothing; you've gotta improvise on something" (Weick, 1998). Thus, to improvise, researchers cannot have empty minds, but open minds allowing the unexpected to occur. They start any given research project with a question that guides their study, but those questions are under constant revision and are continually taking new shapes (Janesick, 2000). This stance implies that the progressive focusing of the research question is not necessarily about constant refinement of the original research question; during the course of inquiry new questions may emerge. As Stake (1995) holds, often the best research questions evolve during the study.

unfamiliarity with the specific context of research. I entered the field guided by the question "What are organizational conditions for radical innovation?" This question was accompanied by the insight obtained from working on the project proposal and a strong willingness to learn and explore during the research process.

7.4 Case Study Design and Choice of Cases

The five 1999 Birkeland Award finalist projects and my research purpose naturally pointed to *qualitative case studies* as a useful approach for studying innovation as a multifaceted phenomenon. In general, case studies are the preferred strategy when "how" or "why" questions are being posed, when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context (Yin, 1989). A case study is not a methodological choice, but a choice of *what* is to be studied (Stake, 2000).[304] A case is a specific, complex, integrated system, and the purpose of a case study is to thoroughly understand the complexity and particularity of the case (Stake, 1995). A qualitative case study is holistic, empirical, interpretive, and emphatic, and it relies on multiple data sources (e.g. interviews, observations, and document reviews). The qualitative researcher is an interpreter and gatherer of interpretations, emphasizing "thick description", "experiential understanding" and "multiple realities". The generated understanding is generalized through theoretical propositions, not to populations.

My primary interest in the Birkeland Award projects was to use the projects to gain new knowledge of organizational conditions for innovation. In accordance with the assessment criteria for the award, the projects exemplified high quality, creativity, and considerable innovativeness. As such, they all appeared relevant for my study. I also believed that a joint study of all the projects would help me understand organizational conditions for innovation better than the study of a single project. The projects covered different subject areas and organizational entities and seemed to be rich, contrasting, and comparable. Therefore, I aimed at doing a *collective case study* (Stake, 1995; 2000), or what Yin (1989) calls a *multiple-case study*.

According to Stake (1995), opportunity to maximize what we can learn is the primary criterion for selection of cases. At the start of my inquiry all the "given" case projects seemed equally suitable for my study. Yet, in the end, my collective case study included only one of the Birkeland Award finalists. My selection process did not follow the

[304] It follows that not all case studies are qualitative (Yin, 1989; Stake, 2000)

replication logic suggested by Yin (1989). Nor was it guided by careful consideration of the uniqueness and contexts of alternative selections. Rather my collection of cases largely emerged from practical concerns and dialogues with managers in Norsk Hydro.

At our meeting in Oslo, the head of the Norsk Hydro corporate R&D group suggested I should study a research project developed at the HA R&D center at Karmøy, rather than the Birkeland Award "aluminum" project. He also said that he would introduce the issue to the research director at Karmøy and ask him to suggest a proper case project. In this way, the PROSMAT Extrusion project emerged as a project representing activities in Hydro Aluminium. During 2000 I had meetings with the research directors at the three Research Centers where the remaining four Birkeland Award projects had been developed. I also visited the Research Center in Porsgrunn, meeting researchers involved in the Omacor™ project, and the so-called MTO project (within the field of petrochemistry). I found that I was in the favorable position of having several interesting case projects available for study. My initial concern was not *which* projects to study, but the *order* in which to study the separate case studies. Which project should I start with? I decided to start with the Omacor™ project and then proceed to the PROSMAT Extrusion project.

During the study of the Omacor™ project I realized that it was a time-consuming, extensive job just to study *its* complexities. Since I aimed at getting a thorough understanding of each case project, my ambition of studying five projects within the scope of a PhD program suddenly appeared unrealistic. In the meantime I had also been informed that the PROSMAT Extrusion project was not one single project, but *three* subprojects highlighting different topics within the field of aluminum extrusion. Taking into account that learning about pharmaceutical product development had proved to be a comprehensive task in itself, a study of three projects belonging to the same "world" appeared as a much better idea than investigating several new subject areas. At the same time, I believed that the three PROSMAT Extrusion projects would provide great opportunities to learn about innovation. So, I abandoned the plan of studying the remaining 1999 Birkeland Award finalist projects, and my collective case study eventually included the three PROSMAT Extrusion projects and the Omacor™ project.

7.5 Field Work and Strategies for Data Gathering

My main sources of data in this study are *interviews* and *document reviews* (Stake, 1995). The field activities spanned the time period from February 2000 to June 2003 (See

Appendix C). During this period I conducted 61 interviews with people in Hydro, researchers at SINTEF, NTNU, and the University of Oslo, and one representative of The Research Council of Norway. I spoke twice with seven informants, and three times with two other informants. The interviews typically lasted one and a half to two hours. Most interviews were audio recorded, and I transcribed most of these. For those interviews I did not tape, I wrote field notes based on my personal notes to reconstruct and reflect the main points of the interview.

I began each interview with a brief outline of its purpose. When intending to audio tape the session, I asked the informants for their permission and stated my reasons for audio taping, guaranteeing individual anonymity. All interviews were prepared and guided by a list of semi-structured, open-ended issue questions (Stake, 1995; Silverman, 2001). For my interviews with participants in the case projects, I used a common interview guide asking each informant the same questions. Still, I asked specific additional questions to clarify or elaborate into topics introduced. When preparing the second or third interview with an informant, I worked out a specific list of questions based on our foregoing conversation and project-relevant issues I wanted to learn more about.

Stake (1995) claims that audiotaping is valuable for catching the exact words used, but that the cost of making transcripts and the annoyance for both respondents and researcher are strong arguments against it. During the 47 audiotaped interviews in this study I was twice requested to turn off the recorder before informants were willing to continue elaborating on apparent “controversial” opinions. At the same time, I did not feel that the recording disturbed the interviews or contributed to a tense atmosphere. Rather, I felt that the interviews took place in a relaxed atmosphere where most informants seem to forget about the tape recorder during the talk.

Recognizing arguments against audio recording and transcription, I still assert that these methods were necessary in light of my purpose of developing a thorough understanding of the case projects. First, since I entered the contexts of drug development and aluminum extrusion with low theoretical sensitivity (Strauss and Corbin, 1990), it was wise to transcribe most of the conversations to avoid missing significant data. I also needed a long time to come to understand what was going on in the projects. As such, transcription proved to be important during the entire data collection period. Second, the transcripts would turn out to be really helpful in my data analysis, assisting me in obtaining the density of the theory I desired (see Chapter 7.5). Third, they facilitated my extensive use of citations in the chapters presenting my analyses and discussions of the data (Chapters 8 through 12). Fourth, my preparation of the transcripts was not simply a technical exercise prior to the analysis, but an essential research activity, or act of *reflective practice* (Silverman, 2000; Schön, 1983). The time-consuming process represented beneficial "periods of ripening." It stimulated far more questions and allowed more in-depth dialogues with the data than merely listening to the tapes, or reading transcripts prepared by others, would have enabled. By listening to, and writing down, my "own" passages, I also got valuable personal feedback helping me to communicate as effectively and well with my informants as possible.

Along with the conversations, a thorough document review was an essential source of information in my study. Having signed a confidentiality agreement, I was given free access to review an extensive amount of relevant project reports, minutes from meetings, correspondence, and organizational records. I also made a review of annual reports and various Hydro magazines spanning from 1985 to 2003. The documents were an important complementary source of information about the case projects. I collected my personal document review notes in electronic files. These comprise about 80 A4 pages for the Omacor™ project and about 20 for the PROSMAT Extrusion projects.

According to Yin (1989), the most important use of documents is to corroborate and augment evidence from other sources. The documents were helpful in verifying the correct spelling of titles and names mentioned in interviews. They also provided other specific details corroborating information from the interviews, for instance information on the dating of events. When the documentary evidence was contradictory rather than corroboratory, I made closer investigations of the topic. Still, even though the documents were useful regarding verification of other sources, they first and foremost helped me to learn more about the case projects. In particular, the comprehensive status reports concerning the Omacor™ project, covering elaborate descriptions of events, actions, and actors' perspectives, provided essential supplementary information on topics mentioned in the interviews. They sensitized me to critical issues, stimulated questions, directed my theoretical sampling (Strauss and Corbin, 1990), and occasionally provided glimpses of sudden insight ("Aha, now his statement makes sense to me!").

During my stays at the Research Centers in Porsgrunn and at Karmøy I aimed at becoming as familiar with Norsk Hydro and about peoples' perspectives on research, creativity, and innovation as possible. Therefore, I made requests for a couple of guided tours. In addition, I had several interesting talks with people who were not participants in the case projects.

7.6 Strategies for Data Analysis

As a grounded theorist I started analysis early, coding my emerging data as I collected it. To make sense of my data, I used the following techniques: *Open coding, the asking of questions* (Strauss and Corbin, 1990; 1998), the *constant comparative method* (Glaser, 1992; Charmaz, 2000), *visual displays* (Ryan and Bernard, 2000), *theoretical sampling* (Strauss and Corbin, 1990; 1998; Seale, 1999; Charmaz, 2000), and *writing* (Richardsson, 2000). Below, I describe how I applied these techniques by using my initial case study (the Omacor™ project) as an example.

Open coding is the process of breaking down, examining, comparing, conceptualizing, and categorizing data (Strauss and Corbin, 1990). This process started the chain of my theory development. During and after my first round of data collection I transcribed the conversations. I coded the transcripts by sentence or paragraph, identifying themes and concepts, and inserting these as *tags* to mark off text for later retrieval (Ryan and Bernard, 2000). Then I "transferred" the individual transcripts to *mind maps* (Buzan, 1985). Each branch of the mind map referred to one specific code and included a reference to the pages where the code was described. As the open coding proceeded, I aimed at linking the coding categories together in theoretical models by making comparisons and asking questions about the data.

The *constant comparative method* in grounded theory means comparing different people, comparing data from individuals with themselves at different points in time, comparing incident with incident, comparing data with category, and comparing a category with other categories (Charmaz, 2000). By means of this method I developed temporary models in the form of concept maps and various matrices, trying to figure out how things were related to one another. To prepare the visual displays I wrote the codes on post-its and grouped the data into three main categories labeled "pharmaceutical product development", "chronological events", and "informants' opinions". Comparing the transcripts, I then made *concept maps* (Novak, 1998) of categories pertaining to "pharmaceutical product development" (e.g. "patents", "approval", "clinical studies"), and various matrices (e.g. time-ordered, person-ordered, issue-ordered matrices in the form of posters with post-its) pertaining to the two other categories. At this point in time, I experienced the data as an overwhelming, messy mass I was not able to make sense of. The matrices and concept maps were rather incomplete, triggering far more questions than answers. Still, my initial analysis, as well as the accompanying diary entries, provided something to improvise on, directing further inquiry.

To fill the conceptual gaps and holes, I conducted *theoretical sampling.* Theoretical sampling is the data collection process whereby the grounded theorist jointly collects, codes, and analyzes data, and decides what data to collect next and where to find it, in order to develop the emerging theory further (Seale, 1999, p. 92[305]). The aim of such sampling is to refine ideas, not to increase the size of the original sample (Charmaz, 2000). The theoretical sampling demanded that I had completed the work of comparing data with data, and had developed a provisional set of relevant categories for explaining the data. In turn, these categories took me back to the field to gain more insight about when, how, and to what extent they were pertinent and useful (ibid.).

Preparing for the second round of data collection, I made specific lists of issue-oriented questions for the interviews with those informants I had already spoken with. In addition, I asked all informants specific questions derived from my initial analysis. During the interviews, names of other relevant informants emerged, guiding further theoretical sampling. Coming home again, I continued my inquiry in the same way as described above - transcribing, studying the document review notes, working on and improving the concept maps and matrices. In turn, I made a new round of data collection, accompanied by new questions and temporary models.[306] In this way, I became more and more “grounded” in the data, and managed to develop increasingly richer concepts and models of the case and of the issues reflected in my research questions.

After the last round of data collection for the Omacor™ project, I continued analyzing in the same manner as before. I also grouped relevant information about specific themes in separate electronic files to facilitate further comparison and subsequent improvement of the models. Next, working on the concept maps and matrices I began to write a draft of the case story, and this process was guided by three main concerns. First, I had a strong desire to develop thorough insight into the case. Without a firm grasp of the complexities of the Omacor™ project, I would not succeed in generating a solid understanding of innovation. Second, recognizing that I had a rich amount of interesting data, I aimed at working out a compositional structure portraying the case in an informative and engaging way. Third, thinking of the case story as a communication device, I aimed at composing the story in a

[305] Seale (1999) quotes Glaser and Strauss (1967, p. 45)

[306] For instance, preparing the interview with the project manager for the scaling-up efforts, I made a concept map based on my review of documents describing this work and asked her to comment on that as part of the interview.

way that would contribute to the reader's understanding of the case.[307] In particular, I tried to tune into the needs of potential readers, primarily colleagues in the field of organization and management.

Since I assumed that most potential readers were unfamiliar with drug development, I found it necessary to write an introductory chapter describing the dynamics of pharmaceutical product development. The writing proved to be an important *method of inquiry* (Richardsson, 2000), representing an ongoing conversation between my data, my emerging theoretical models, and my attempts to formulate increasingly clearer formulations of the grounded theories. The process helped me to make better sense of the data, learning things about pharmaceutical product development that I did not know before writing about it. Similarly, writing the chronological overview and the subsequent comprehensive case story was important for developing an in-depth understanding of the case. I realized that writing a case story was not simply a "reporting" activity following a complete analysis, but an essential part of grounded theory building, as discussed by Charmaz (2000).

I also learned that I could not wait to write until I had found the "perfect" compositional structure. Having spent (too) much time trying to generate "The Structure", I realized I just had to start. I began with the section describing patent work. To my great surprise, I experienced that the organization of the thematic chapters and overall structure emerged from the writing; it was grounded in the writing in the same way my theories were grounded in my data.

I completed the case study of the Omacor™ project before I moved on to the PROSMAT Extrusion projects. As such, I could benefit from the lessons learned so far. Below, I briefly outline how some of these guided my further inquiry.

The first lesson concerned the feeling of being overwhelmed by impressions when entering an unfamiliar context. I illustrate this through the following excerpt from a diary entry made in September 2002:

> *…I think that doing case studies of industrial research projects is similar to entering entirely different worlds or planets. At least, that is what it feels like! …After my first conversations with the Omacor™ researchers (who are specialists in their field and used to talk to insiders, naturally enough), I concluded that this can't be very different from talking with Martians. I remember feeling really lost during the first period of this case study…**This time I know what it is like to enter a***

[307] The case story in question, as well as the comprehensive case stories of the three other case projects, constituted Volume II of the original version of this thesis. These case stories are left out of this version.

> ***new planet, and I have started the entry***. *A friend of mine working at SINTEF has given me a brief introduction to extrusion technology. In addition, I took part in a seminar on aluminum research in Oslo last week. Most of the presentations were like Greek to me, bla bla bla (It was really hard to stay awake – I made notes most of the time to appear "interested" and to avoid falling asleep), but I met some of the people I am going to interview/have conversations with next week and I got a tiny, tiny idea of some of the fundamental research challenges of aluminum both in academia and Hydro Aluminium. I feel more relaxed, now...I realize that I am not supposed to know everything about the actual technology - just enough to be able to catch the issues I am interested in. Moreover, I know it will take me time to find out about things. So, I have to be patient…*

Another lesson concerned the way I checked my interpretations and understanding with researchers during interviews. During the Omacor™ project I had prepared written questions. However, I often found it difficult to formulate clear questions and constructions of meaning. Likely, this was because I did not have the necessary knowledge to transform my "fuzzy" understanding into well-spoken explicit terms. At least, this was one of the conclusions I drew from listening to and transcribing the comments I made during the interviews. Therefore, during the study of the PROSMAT Extrusion projects I put stronger emphasis on concept maps and other visual displays to support my questions. This proved to be a sound strategy, facilitating the externalization of my understanding as well as the communication between me and the informants. Finally, during my study I also learned that some of my informants were particularly good at explaining complex technical issues in a simple way. For this reason, I used these people as key informants – or "teachers" – regarding issues around aluminium extrusion and modeling.

7.7 The Trustworthiness of the Study

As is evident from the foregoing chapters, the most salient feature of a constructivist grounded theory and attention to qualitative case studies is attention to *interpretation*. During my inquiry I have been an ongoing interpreter and gatherer of interpretations (Stake, 1995), focusing on "multiple constructed realities," rather than a single, universal, and lasting reality. Ergo, the interpretations I present in this thesis are not the only possible ones. I have constructed an image of *a* reality, not *the* reality, in interaction with my informants (Charmaz, 2000).

To evaluate the quality and validity of my constructed reality I will use the criteria recommended by Lincoln and Guba (1985). Arguing that the conventional trustworthiness criteria are inappropriate to constructivist research, Lincoln and Guba proposed the following substitute criteria: *Credibility* (paralleling internal validity), *transferability* (paralleling external validity), *dependability* (paralleling reliability), and *confirmability* (paralleling objectivity). The authors also recommended a set of techniques that could be used to affirm trustworthiness. I now go on to discuss the trustworthiness of my study in light of Lincoln and Guba's proposed criteria and corresponding procedures.

7.7.1 Credibility

Credibility concerns the question of how to establish "truth value" of the findings in a study carried out in a specific context (Lincoln and Guba, 1985). In order to demonstrate "truth value" I must show that I have represented the multiple constructed realities in my material in an acceptable way (ibid.). That is, I need to show that my findings and interpretations (reconstructions) are credible to those who constructed the realities, namely my informants. More specifically, I have to demonstrate that my study increased the probability of credible findings, and that my findings were approved by my informants.

Lincoln and Guba (1985) call attention to seven techniques useful in establishing credibility: *Prolonged engagement*, *persistent observation*, *triangulation*, *peer debriefing*, *negative case analysis*, *referential adequacy*, and *member checking*.

Prolonged engagement is about spending sufficient time on site to develop a thorough understanding of the research context, to build trust among the researchers and the informants, and to decrease the likelihood of data distortion introduced by the researcher or the informants. My grounded theory approach, including the necessity of theoretical sampling, naturally implied that I could not develop a solid grounded theory through one-shot interviewing in a single data collection phase (Charmaz, 2000). I conducted the collective case study over a period of three and a half years (from February 2000 to June 2003), including the meetings preceding the periods of intensive data collection (See Appendix C). Through "member checking" activities I also had contact with informants via telephone or e-mail over the next three years. Accordingly, I thus argue that I am able to demonstrate a prolonged period of engagement.

The technique called *persistent observation* provides depth of understanding by identifying the salient characteristics most relevant for the focus of the study. To sort out those things that really count, the researcher must continuously engage in tentative labeling and exploration of salient factors, and try to avoid premature closure. My grounded theory approach in combination with the duration of the study provided me with an ever-increasing degree of theoretical sensitivity, that is, insight into the complexity of the case projects, the ability to make sense of the data, the capacity to understand, and the capability to separate the pertinent from the non-pertinent (Strauss and Corbin, 1990). The following excerpt from a diary entry highlighting reflections on my first case study may serve as an illustration here. Referring to the first period of this study I wrote:

> *…..Another issue that kept my mind busy was the question: How deeply and thoroughly do I have to investigate the world of omega- 3 fatty acids and pharmacy in order to deal well with my research questions? For instance, do I have to understand the so-called biosynthesis with its complex pattern of enzymes, prostaglandins or whatever these substances are called? Initially I tried very hard to understand, but had to give up and think realistically. With time, I realized two things: First, I am not supposed to understand a technological or scientific field to the same degree as the researchers themselves, and this fact does not make me "stupid." I clearly see that know. I also realize that the first case study was a good case of research itself: Research is inevitably about some trial and error. You cannot precisely know in advance how much or how deeply you have to investigate or understand a phenomenon. The "answers" appear as part of a continuous process of reflection and experience…*

I thus claim that I used persistent observation in a way that increased the credibility of my study.

Triangulation involves the use of multiple data sources, methods, investigators, or theories to test whether different perspectives converge on a single version of reality (Seale, 1999).[308] The more different perspectives unite, the higher the likelihood that findings and interpretations will be found credible. In my study I have used *methodological triangulation* and the overlapping *data source triangulation* (Lincoln and Guba, 1985, Stake, 1995, Seale, 1999).Methodological triangulation involves using more than one method for data collection (observation, interview, document review), while the use of multiple data sources implies *multiple* copies of one type of source or *different* sources of the same information. During my study I interviewed several informants about the same case. In addition, I made a thorough document review. The document review was useful regarding verification of informants' recollections about aspects of the case projects (Ref. Chapter 7.5). As such, triangulation helped me avoid biases resulting from reliance on one method only (Seale, 1999). Still, my use of several sources and methods primarily helped

[308] In a strict sense, the idea of triangulation reflects the positivist assumption that a single, fixed, objective reality exists. As such, its usefulness within constructivist inquiry is disputed (Seale, 1999).

me learn more about the individual cases, showing that triangulation can serve purposes other that the validation of one account (ibid.). Therefore, I argue that triangulation increased the credibility of my findings by enabling verification of data as well as a deepened understanding of the case projects.

Peer debriefing is an activity that provides an external check of the research process. It is a process of exposing oneself to a disinterested peer to explore, clarify, and make explicit aspects of one's inquiry. During my study, the regular advisory sessions with my adviser have been the most significant context for peer review. Discussions and meetings with research fellows in the Research community at Dragvoll gård have also been important. In addition, the various PhD courses, including oral and written discussions (exam papers), have contributed to a deeper understanding of my research topic as well as better insight into what research is all about.

The technique of *negative case analysis* involves continuous systematic testing of one's understanding against new data. Since such testing is a natural part of grounded theory building, I applied it regularly during my research process.

Referential adequacy involves the use of video recorded or audio recorded "raw data" as a benchmark for later testing of preliminary findings and interpretations. I audio recorded most of the conversations with my informants. However, I recorded the sessions on the condition that the tapes would *not* be made accessible to others; the audio recording was solely a means for *me* to gain insight into the case. Referential adequacy was therefore an irrelevant method, incompatible with the trustful and confidential relationship that allowed audio recording in the first place.

Finally, *member checking*, regarded as the most crucial technique for establishing credibility, provides for the direct testing of findings and interpretations with the informants. First, I emphasized reformulation and testing of interpretations (Kolb et al., 1986) during conversations to foster effective communication. Second, I regularly presented draft materials to informants for confirmation and further illumination. For instance, I often discussed concept maps or transcribed excerpts from a previous meeting with informants during the next interview. Third, I sent drafts of the various case stories to informants. To highlight issues needing further clarification, I entered distinct questions in the texts to specify issues that needed further clarification. I found the member checking technique highly useful. The fact that most informants provided feedback on the drafts of the case stories helped me minimize misinterpretation and misunderstanding (Stake, 1995). It also provided additional or more elaborate data, because informants often recalled or clarified things they did not mention the first time around. Furthermore, I used member checking to uncover the question of anonymity regarding the case stories. Expecting my informants to prefer their names be withheld, I used fictitious names in the drafts and asked for explicit feedback on this practice. To my surprise, all informants allowed me to use their real names. Some even argued that accurate identification of participants in the projects was preferable, making the story easier to read. Along with my finding that most feedback concerned minor issues such as spelling mistakes and response to specific questions, I regard this approval as a strong confirmation of perceived credibility. Thus, my attention to member checking has been useful in establishing what Lincoln and Guba (1985, p. 315) describes as “a strong beachhead toward convincing readers and critics of the authenticity” of my work.

All together, I find that my application of techniques for establishing credibility shows that my study may be regarded as highly credible.

7.7.2 Transferability

Transferability deals with the problem of knowing whether a study’s findings are applicable to other contexts beyond the actual case. Within constructivist research, the establishment of external validity is, in a strict sense, impossible (Lincoln and Guba, 1985). The researcher cannot know the contexts to which the findings may be applied, but the appliers can and do. As such, the main responsibility of the researcher is to provide a “thick description” of the empirical data and of the time, place, and context of the study to enable those interesting in making a transfer to evaluate whether this is possible. As Stake (1995) holds, a constructivist view encourages researchers to offer readers good raw material for their own generalizations.

I claim that I have provided sufficiently rich descriptions to make it possible for readers to evaluate the transferability of my findings. My overall presentation of my empirical data is extensive, elaborate, and thorough. It comprises the narratives in Chapter 6 as well as the comprehensive cross-case analysis and discussion presented in Chapters 8 through 12 (Part III).[309] Furthermore, as the findings are derived from a collective case study including four cases, they indicate a certain level of transcontextual credibility and robustness (Finsrud, 2004). Yet, in the last instance it is the reader who decides the question of transferability. I

[309] In addition, it comprises the comprehensive case stories constituting Volume II of the original version of this thesis.

thus conclude that I cannot demonstrate transferability of my study, but that a transfer of my findings to other contexts is likely.

7.7.3 Dependability

The criterion of dependability concerns the question of consistency: How can we be sure that our findings will be repeated if other researchers replicate our study with the same (or similar) informants in the same (or similar) context? Because dependability is a precondition for credibility, demonstration of credibility is sufficient to establish dependability in practice. Still, Lincoln and Guba (1985) argue that it is necessary to deal with dependability directly, proposing the *inquiry audit* as a proper method. Inquiry audit is based metaphorically on the fiscal audit and implies that the auditor examines the process and products of inquiry. Attestation of the process establishes dependability, while affirmation of the product determines confirmability (see Chapter 7.6.4).

My research process has not been subject to an external audit, nor do I regard this method as useful in determining dependability. First, for reasons of confidentiality and trust, my research material is not accessible to others (Ref. my earlier discussion on *referential adequacy*). Second, if my data were accessible, the involvement of an external auditor would be too resource-demanding within the limits of a PhD study. Third, since my research process emerged in close dialogue with myself, my informants, and my data in a specific contextual setting, it is not likely that an inquiry audit will manage to take account of the context-centeredness of the study (see further discussion in Chapter 7.7.4). Following Finsrud (2004), I argue that the quality of the dependability criterion rests on my close relationship with the field over time, and my regular advisory sessions as part of the PhD study. In addition, my emphasis on keeping a diary (or *reflexive journal* in the terms of Lincoln and Guba (1985)) with reflections on most aspects of my research process probably enabled me to conduct a more dependable process than would otherwise have been the case.

Summing up, I conclude that I have not conducted a direct validation of dependability. Still, recalling the argument that dependability is a prerequisite for credibility, I argue that my previous demonstration of credibility proves that my findings may be regarded as dependable in practice.

7.7.4 Confirmability

Confirmability concerns the question of how to ensure that research findings are determined by the subjects and conditions of the inquiry and not by the biases, motivations, interests, or perspectives of the inquirer. The major technique for establishing confirmability is the *confirmability audit*, that is, the examination of the *product* of inquiry (e.g. the data, findings, interpretations, and recommendations) to decide whether the findings are grounded in events or in the researcher's personal constructions (Lincoln and Guba, 1985).

As indicated, my study has not been audited in the way proposed by Lincoln and Guba (1985). In addition to the arguments presented above, I question the appropriateness of doing such an audit in the first place. First, taking account of my ontological position, it is unlikely that other researchers will arrive at the same conclusions based on access to the same data ("raw data", concept maps, diary notes, etc.). Accordingly, the very criterion of confirmability seems inappropriate within a constructivist perspective. Second, the record I would have to offer an external auditor would not represent the exact same data that guided my study. At best, they would represent a broad selection of my material. My findings and conclusions have emerged from a lengthy research process spanning several years. As such, it is unrealistic to assume that I have explicitly stated the reasons behind every inference or every interpretation I have made. Much of my research process remains tacit in terms of assumptions, reflections, and contextual knowledge hardly accessible to external audits. Furthermore, my field notes and diary entries are *reconstructions* of issues attracting my attention during the inquiry. These records reflect my theoretical sensitivity and interests at specific points in time and do not give an account of possible, equally attractive issues. Third, I find it unlikely that an external audit spanning a week or ten days (Ref. Lincoln and Guba, 1985, p. 325) would make the auditor sufficiently acquainted with a complex, long-term research process. Proper evaluations of the "objectivity" of the study require considerable knowledge about the research context that cannot be acquired simply through reading.

Attention to *maintaining a chain of evidence* (Yin, 1989) seems to be a better strategy for establishing confirmability. The principle is to allow readers of research reports to follow the derivation of any evidence from initial research questions to ultimate conclusions. Although this technique reflects some of the problematic assumptions outlined above, it reminds the researcher of the responsibility to compose the report in such a manner that the link between research questions, analysis, discussion, and conclusion becomes clear. In writing this thesis I have put effort into communicating my chain of evidence as clearly as possible, in particular through the structure of Chapters 8 through 12 (Part III). Still, it is the readers who in the last instance determine whether my findings are confirmable.

I conclude that I have not demonstrated confirmability and that demonstration of this criterion appears inappropriate within a constructivist perspective. At the same time, I assume that my attempt to display a chain of evidence in the thesis makes it likely that my findings will be found confirmable.

7.7.5 Conclusion

Based on the foregoing discussions of trustworthiness criteria I conclude that my study is sufficiently trustworthy. The study's credibility is high and its transferability is likely, but not demonstrated. Its dependability is probably high, but not directly verified. Confirmability is likely, but I do not consider confirmability as a relevant criterion from my constructivist point of view.

Part III: Analysis and Discussion

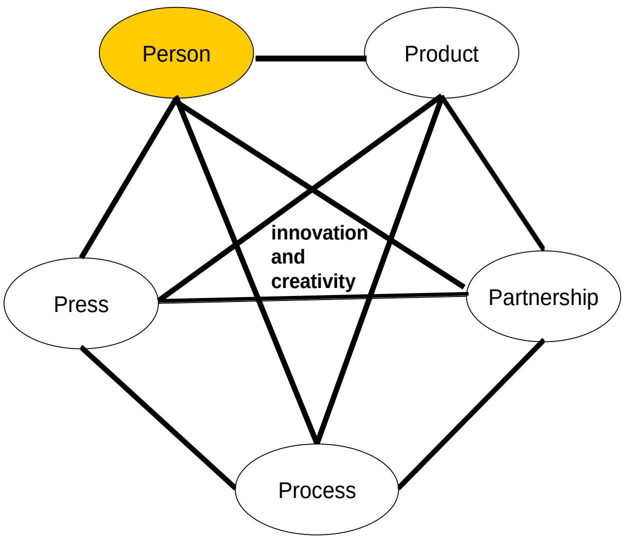
In this part of the thesis I analyze and discuss my empirical data in light of the 5P diamond model of innovation and creativity. Chapters 8 through 12 present my analysis and discussion of the *Person*, *Press*, *Product*, *Process*, and *Partnership* facets of the data, respectively, and are structured according to the facet-specific research questions presented in Chapter 5. The analyses and discussions presuppose that the readers have acquainted themselves with the case projects in terms of the chronological overviews and outline of relevant concepts and topics presented in Chapter 6.[310] Each of the Chapters 8 through 12 provides an adequate review of relevant data, meaning the chapters can be read independently of each other. For this reason, some empirical examples recur throughout the facet-specific analyses and discussions.

[310] Glossaries for aluminum extrusion and pharmaceutical product development are given in Appendices A and B.

Chapter 8 Analysis and Discussion of the Person Facet of Innovation and Creativity

8.1 Introduction

In this chapter I discuss my empirical data in light of the *Person* facet of innovation and creativity. I focus on individual knowledge, skills, and actions promoting innovation, structuring the analysis and discussion around the facet-specific research question presented in Chapter 5.3 (see below). In the following I call attention to those persons who stand out as the best examples of how individuals positively influence innovation. To enable a proper review of empirical data I frame the individual contributions by presenting the context of the persons' activity.



Research Question in Terms of the Person Facet of Innovation and Creativity *What are salient characteristics of individual contributions promoting innovation?*

8.2 What are Salient Characteristics of Individual Contributions Promoting Innovation?

8.2.1 A Presentation of Individual Contributions in the Case Projects.

The Omacor™ Project

I start this chapter by shedding light on the individual contributions of three participants in the Omacor™ project: The Hydro researcher proposing the idea of developing an omega-3 "heart medicine", the project manager of the Omacor™ project, and the Vice President of the Hydro Agriculture Business Unit.

The origin of the Omacor™ project was a research project aimed at developing a process for extracting enzymes from fish waste.[311] The process provided enzymes, but also a fatty by-product "that we constantly had to make an effort to get rid off", as the project manager Sigurd Gulbrandsen expressed himself. The emergence of the "problematic" fat raised the question of what to do with it. Gulbrandsen applied to Norwegian research groups to discuss the possibility of a commercial utilization. Among others, he contacted *Bernt Børretzen*, an organic chemist he knew at the Norsk Hydro Research Center in Porsgrunn.

Børretzen had been with Hydro for many years, working in the field of organic chemistry. He had recently returned to Hydro after spending about 20 years with a pharmaceutical company in Sweden. When asked about the commercial potential of the fish fat, Børretzen responded immediately, suggesting that the omega-3 fatty acids in the fish fat could form the basis for a high-concentrate omega-3 "heart medicine". He argued that the use of omega-3 for medical treatment was a new, expanding field with a great potential. Børretzen also emphasized that the development of a high-concentrate "was the very point": If a medical treatment should be possible, the purity had to be high so that patients were given a reasonable low volume.[312]

Børretzen's response was based on his previous experience from the pharmaceutical company in Sweden. According to him, Sweden "has always been *far* advanced concerning pharmaceutical research and development". In Sweden (and in Norway as well), omega-3 fatty acids and related organic compounds had been the focus of extensive research for

[311] Ref. Chapter 6.6
[312] Svendsen (1996)

more than fifty years, and Børretzen was familiar with the major works on omega-3 and their biological effects. He was also informed about current work on the omega-3 fatty acid *EPA*, performed by a large research group at a Swedish hospital. As such, Børretzen had considerable knowledge on current trends in pharmacy and research on omega-3 that added strength to his idea of developing a "heart medicine" from the fish fat. His "input" became part of a document on fine-chemicals from fish waste that the "enzyme" project manager Gulbrandsen wrote in May 1984. Thus, Børretzen clearly promoted the project idea by means of his object-specific know-how, thereby acting as a *promotor of know-how*[313]. Possibly, the Omacor™ project would not have become a reality if it were not for Børretzen's specific knowledge of relevance for the discussions on the commercial potential of the fish fat.

Apart from being a *promotor of know-how*, Børretzen acted as a *product champion*[314], actively and intensively promoting the project idea to gain critical support from top management. In addition, he filled the role as an *intrapreneur*[315], working hard to turn his visions into action. Børretzen was known as a man providing entrepreneurial spirit, creating ideas and pushing projects.[316] He is characterized as the champion chemist behind not only the Omacor™ project, but a number of other projects in the field of organic chemistry.[317] From 1985 onwards, Børretzen was involved in the Omacor™ project and several other projects, among others, a project directed at developing a cancer medicine based on Hydro' traditional deuterium technology. He worked part-time in Hydro Innovation[318], commuting between the Hydro headquarters in Oslo and the Research Center in Porsgrunn. Børretzen, who is typically described as "the creative force behind an entire professional team[319], acted as an all-round person providing general assistance to the Omacor™ project, contributing "when and where it was needed," as he put it, adding:

> *…I acted more or less as a project manager in the beginning, took part in the chemical research, the arrangement of semi-technical experiments and pre-clinical studies, carried out administrative tasks, launched the project in Norsk Hydro – the whole part of it...*

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[313] Ref. Witte (1977)
[314] Ref. Schön (1963); Chakrabarti (1974)
[315] Ref. Pinchot (1985); Hébert and Link (1988); Kao (1991); Casson (2003).
[316] Svendsen (1996)
[317] Source: Speech to the Birkeland Award finalists 1999 made by Knut Harg.
[318] Hydro Innovation was a new business division responsible for the exploration and development of new business ideas within the areas of biotechnology, materials technology, and offshore (Ref Chapter 6.6).
[319] Source: Speech to the Birkeland Award finalists 1999 made by Knut Harg.

Some project members remarked that people at Hydro's head office seemed to regard Børretzen as the senior manager of the Omacor™ project even though he was not the formal manager of the research part. Børretzen had an extensive network that included almost everyone in Hydro's headquarters. He devoted much effort to championing the Omacor™ project, presenting ideas and discussing relevant issues with top managers. Børretzen has a rather unconventional style, emphasizing the importance of informal talks and discussions. He recounted:

> *…I talk to people a lot. I'm not a particularly modest person (ha ha), I enter people's offices to have a talk…I was used to that from Sweden – they talk a lot more than we do. They have quite another R&D culture than we have in Norway…*

Through his boldness and way of working, Børretzen managed to obtain critical support from top managers. His power of conviction may be illustrated by the following example concerning the project budget: *In 1985 the project activities progressed quickly, exceeding the initial budget of NOK 400,000. Initially, the budget was increased to NOK 500,000, then finally to NOK 800,000. The original budget for 1986 was NOK 400,000. It was soon increased to NOK 500,000, then to NOK 1,000,000 in June and finally to NOK 1,600,000 in the end of the year, i.e. four times the initial budget.*[320]

Generally, project members agree that the project "would *never* have been carried out" if it were not for Børretzen's contribution to the project. In the words of a project member: "*He provided money, he took part in all important meetings and presentations, and he played a decisive role concerning patent protection.*" Similarly, another project member claimed:

> *…The project would **never** have come through if it wasn't for his knowledge, extensive network and role as a great source of inspiration. He knew a lot about pharmacy, production facilities and things concerning official authorities, etc., that is, actually, really important factual knowledge – and he had a network outside Hydro we could take advantage of…*

In 1999, Børretzen won the *Birkeland Award for Excellent Research in Norsk Hydro* for his role in the Omacor™ project.

Clearly, Børretzen's personal characteristics and actions go well with the product champion "script" presented in Chapter 5.3.5: Børretzen was strongly committed to the

[320] Svendsen (1996)

project idea, he had considerable power in the company, and he knew and knew *how* to use the company's informal systems of relationships.[321] He also had broad all-round knowledge, drive, aggressiveness, and political skills.[322] Furthermore, Børretzen's extroverted style and action-orientation with an unstoppable need to turn vision into action are traits associated with entrepreneurs/intrapreneurs.[323]

In sum, the personal traits, knowledge and skills portrayed in Børretzen's overlapping roles as *promotor of know-how*, *product champion,* and *intrapreneur* call attention to two basic components underlying his powerful promotion of the Omacor™ project: *Political skills* and *relevant knowledge of the problem context*. Clearly, Børretzen's political skills positively influenced the progress of the Omacor™ project. These skills, fostered by his extroverted style (*"I talk to people a lot"*), drive, boldness and emphasis on informal talks ("*I'm not a particularly modest person (ha ha), I enter people's offices to have a talk*"), were essential for his capacity to convince top management about the virtue of the project. At the same time, it is natural to assume that Børretzen's extensive *personal network*, which covered almost everyone in the Hydro headquarters, boosted his capacity to enlist the necessary support in the first place. Similarly, his external network seems to have facilitated access to critical resources necessary to deal with critical project tasks ("*he had a network outside Hydro that we could take advantage of*"). This brings the concept *social capital* into focus.

Social capital may be defined as the ability of actors to secure benefits by virtue of membership in social networks or other social structures (Hooker et al., 2003).[324] Broadly speaking, social capital is about "making possible the achievement of certain ends that would not be attainable in its absence" (ibid., p.232[325]). Thus, apart from being a *promotor of know-how*, *product champion*, and *intrapreneur*, Børretzen may also be regarded as a *promotor of social capital*.

Along with his strong political skills, Børretzen's *relevant knowledge of the problem context* is a salient characteristic of his individual contribution. As discussed earlier, his knowledge of omega-3 research and current trends in pharmaceutical product development was important for gaining support from top managers. At the same time, Børretzen's

[321] Ref. Schön (1963)
[322] Ref. Chakrabarti (1974)
[323] Ref. Pinchot (1985); Hébert and Link (1988); Kao (1991); Casson (2003).
[324] According to Hooker et al. (2003) this is now a consensual definition of social capital among sociologists. I base my discussion on this broad definition rather than Bordieu's more limited definition concerning the intangible factors that contribute strongly to children's educational achievement and later career success.
[325] Hooker et al. (2003) here cites Coleman (1990, p.304). The specific reference is COLEMAN, J. Social capital. In COLEMAN, J. *Foundations of social theory,* p. 300-324. Cambridge, MA: Belknap Press of Harvard University Press, 1990.

knowledge of issues pertaining to pharmaceutical product development was critical since Hydro had no previous experience with this particular business. His all-round knowledge (e.g. knowledge of pharmacy, production facilities, market trends, issues concerning governmental regulations and institutional arrangements etc.) clearly facilitated the project members' capacity to accomplish their work. Thus, Børretzen's relevant knowledge of the problem context, or what may be called *context-relevant skills*, positively influenced the success of the Omacor™ project.[326]

I now call attention to *Harald Breivik*, the project manager of the Omacor™ project. To properly present his contribution I first introduce the context of his work.

As mentioned above, the Omacor™ project implied for Norsk Hydro to enter into the complex world of pharmaceutical product development in which the company had no previous experience. This world represents the open-ended task of dealing with the "pharmaceutical" and "commercial" challenges respectively.[327] The "pharmaceutical" challenge, covering the work needed to obtain *marketing authorization*[328], implies that the quality of a therapeutic pharmaceutical has to meet the comprehensive requirements of Good Manufacturing Practice (GMP). The obtainment of the required documentation for the *chemical-pharmaceutical file*[329] is a comprehensive and demanding task in itself. For Hydro these efforts implied an even greater challenge since medical product development was new to the company, and because no other Norwegian companies had a competent knowledge of original pharmaceutical development. In the words of a project member:

> *…Both GMP and GLP were unplowed ground at that time. There was really no one in Hydro who was familiar with these regulations. Some had some theoretical knowledge, but* ***no one had a practical experience with these things****: No one had made protocols - procedures for monitoring GMP-based processes. That was very difficult because we knew that our documentation was essential for the application for product approval...*(emphasis is mine)

In addition, the fish fat exemplified an unusually complex raw material since fish oils are composite substances, and because omega-3 fatty acids are chemically unstable.[330] As such,

[326] I simply label relevant knowledge of the problem context "context-relevant skills" rather than contextual knowledge since the label in question is consistent with Amabile's usage (Ref. the concepts "domain-relevant skills" and "creativity-relevant skills" proposed in Amabile (1983a/b;1988).
[327] Ref. Chapter 6.5.2.
[328] The license to sell and market the drug to patients and physicians (Ref. Chapter 6.5.2)
[329] The *chemical-pharmaceutical file* covers the overall documentation of the development and manufacturing of a new therapeutic pharmaceutical required for the application for marketing authorization for a new therapeutic pharmaceutical in accordance with GMP.
[330] Most often, therapeutic pharmaceuticals are composed of synthetic compounds.

the very obtainment of a stable omega-3 high-concentrate is always difficult. Accordingly, the aim of developing an omega-3 medicine in accordance with GMP represented an extraordinary great challenge for the Hydro researchers who became involved in these efforts. Still, the Hydro researchers at the Norsk Hydro Research Center in Porsgrunn succeeded. Not only that, during the project period the researchers at the Research Center in Porsgrunn gained international recognition for their work on omega-3 high-concentrates, and the project manager became a member of a European expert group in the field.[331] *Harald Breivik*, the project manager, contributed strongly to the success, not least through his emphasis on establishing contact with external research groups and internationally recognized experts on omega-3 fatty acids and pharmaceutical product development.

Harald Breivik was a senior researcher at the Analytical department. He had a PhD in organic chemistry and had been at the Research Center since 1980. Breivik had been engaged in work aimed at the introduction of new analytical methods for the Research Center, and he had also worked on PVC-projects. Breivik found the idea of exploring the fish fat highly interesting and was motivated to enter into new challenges. Since he had studied medical chemistry[332] as part of his PhD program, he took a particular interest in the idea of developing a therapeutic pharmaceutical.

Breivik was in charge of the work aimed at developing the omega-3 high-concentrate and the production process in accordance with GMP. He was strongly committed to the project and stayed loyally with it even though he was offered interesting jobs elsewhere during the project period. His personal style and contribution to the project is described as unique: "*He had strong professional pride, but no special personal prestige regarding his own ideas or principles. The important thing for him was the success of the project*," one of his project colleagues commented.

Clearly, the project manager's expertise on the analysis of organic compounds was important for succeeding with the "pharmaceutical challenge". In fact, several project members point to the professional expertise of the project team as a major factor of success. One of them remarked:

[331] The name of the expert group is "The group of Experts for Fatty Oils and Derivatives for the European Pharmacopoeia Commission".
[332] Simply speaking, medical chemistry concern issues on the conceptual thinking related to pharmaceutical product development

> *…I think one may say that we made solid craft. For instance, if you asked professionals in the area, I think they would claim that these researchers are really clever. No one regarded us as charlatans…*

Still, the project members' *domain-relevant skills*[333] in terms of all-round expertise on the analysis of organic compounds were not sufficient to obtain the documentation required by GMP. Breivik recognized that he and his teammates had to become experts in the specific fields of omega-3 fatty acids and pharmaceutical product development. In particular, they had to acquire specialist knowledge of how to analyze omega-3 concentrates and learn how to perform the procedures for monitoring the product and production process. In other words, the members of the project team had to acquire *context-relevant skills*.

Breivik's attention to *context-relevant skills* is also reflected in his emphasis on acquainting himself with relevant omega-3 research and current market trends. His study soon revealed important problems adding further complexity to the efforts of developing an omega-3 medicine. First, Breivik observed that environmental pollution agents such as dioxin and PCB represented an issue of rapidly growing public interest. For this reason, he concluded that the project team had to devote attention to the analysis and removal of such components to avoid future problems. Second, Breivik recognized that the project team had entered a field in which standardized analytical methods were lacking. Different methods for analysis of omega-3 fatty acids provided different results, meaning analysis results often varied from laboratory to laboratory. As a consequence, label claims for omega-3 products did not necessarily contain adequate information for the customer since specifications were always related to the particular test procedure used. In addition, the absolute difference between results from different test procedures normally increased with increasing concentration of the object of analysis.[334] This was particularly unfavorable in light of Hydro's aim of developing an omega-3 *high*-concentrate. Breivik also discovered that some firms used this situation deliberately to bring up omega-3 values in their products to win market shares. In this connection, he also noticed that omega-3 products were suffering from decreasing interest and a bad image due to a great number of low-quality products in the market.

Breivik concluded that the lack of standardized analyzing methods for omega-3 fatty acids might cause misunderstandings and excess work regarding collaborating partners and

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[333] Ref. Amabile (1983a/b;1988; 1996)

[334] "Validation of a Method for Gas Chromatographic Analysis of Eicosapentaenoic Acid and Docosahexaenoic Acid as Active Ingredients in Medicinal Products" (Tande, Breivik, and Aasoldsen) JAOCS, Vol. 69, no.11 (November 1992)

the documentation efforts.[335] As a consequence, he spoke in favor of taking active part in efforts directed at the development and definition of standard international methods of analysis for omega-3 concentrates. Breivik argued that such efforts would give the Hydro researchers additional professional weight.[336] At the same time, active involvement could prevent approval of methods of analysis that might "discriminate" *k85*[337] and other high-concentrates of omega-3. Breivik also claimed that a strong overall emphasis on methods of analysis was necessary to create a spotless image of Hydro's omega-3 products in the market currently associated with non-serious actors and low-quality products. Careful attention to analyzing methods would therefore contribute to giving Hydro a distinguished competitive advantage.

Thus, to summarize, Breivik's recognition of the importance of acquainting himself with omega-3 research and market trends of omega-3 products provided significant knowledge of the problem context directing his attention toward critical factors of success. Evidently, these *context-relevant skills* were of vital importance for dealing with both the "pharmaceutical" and "commercial" challenge, as discussed below.

To cope with the composite problems described above, Breivik emphasized the importance of establishing contact and collaboration with external specialists and research groups.[338] Among others, he established contact with two world-leading experts on marine oils. One of them was a professor at the Canadian Institute of Fisheries Technology. He headed the most internationally acknowledged laboratory for the analysis of omega-3 fatty acids, and his methods for chemical analysis were internationally recognized.[339] Breivik assumed that acquisition of these methods would be critical for dealing with questions surrounding the documentation of purity, by-products, etc.[340] Breivik and his colleagues made several visits to the professor's laboratory to discuss relevant issues, to learn about his methods, to perform analyses, and to compare his methods with the methods used at the Hydro Research Center, Porsgrunn, and at other research laboratories.

The Hydro researchers were also in close contact with a professor employed in the National Analytic Issues Service (NAIS) with the US Department of Commerce. She headed a laboratory that produced a substance similar to *k85* as a test substance for the

[335] "Prosjektoppdrag: Finkjemikalier fra fiskeavfall. Budsjett 1988"
[336] "Konsentrater av omega-3 fettsyrer. Status april 1988" 1988-04-27
[337] "*K85"* was the unofficial name of the 85% omega-3 concentrate that became Omacor™.
[338] Chapter 12.6 gives richer presentation of the comprehensive network of specialists established to deal with the aim of developing an omega-3 high-concentrate and production process in accordance with GMP.
[339] "Omega3-konsentrater fra fiskeoljer. Status februar 1987". 1987-02-27
[340] "Produksjon av ω3-konsentrater, EPA og DHA. Status august 1986".

National Institute of Health. According to The Freedom of Information Act, the NAIS-work was public, providing access to process information such as complete journals for production and analysis. The Hydro researchers had several stays at the NAIS laboratory, studying journals and observing how the documentation efforts were carried out in practice. "*It was very important that we had access to the NAIS system*", Breivik stated.

The regular contact with the professors (and other world-leading experts) facilitated the acquisition of *context-relevant skills* required to meet the directions of GMP. In addition, the opportunities to discuss important project aspects with leading researchers gave Breivik and his colleagues the chance to stay ahead of potential problems such as patent applications and the publicity on environmental pollution. Several project members point out that Breivik's emphasis on making contact with internationally recognized experts on omega-3 fatty acids and pharmaceutical product development contributed to their success in developing an omega-3 medicine in accordance with GMP. "*The fact that he managed to establish contact with almost all the world and his wife, was of decisive importance for the project*," a project member stated. Also Breivik himself called attention to the significance of establishing contact with external experts. He said:

> *…Apart from having staying power, being wilful, and committed to the process, I think my establishment of contacts in several different communities was decisive for the entire development of the project…*

Breivik's approach indicates that *know-who* is a salient characteristic of his contribution to the Omacor™ project. *Know-who* refers to a mix of different kinds of skills, including factual information as well as interpersonal skills (Foray and Lundvall, 1996). Know-who involves information about who knows what, and who knows *how* to do what. In particular, it involves the formation of special social relationships with the expertise involved that makes it possible to get access to and use their knowledge efficiently. Accordingly, Breivik' *know-who* positively influenced the success of the Omacor™ project. Breivik may thus be regarded as a *strategic networker* possessing the entrepreneurial capacity to involve good people.[341]

The significance of Breivik's *know-who* is further illustrated through the coming examples of how he actively encouraged the successful achievement of critical project tasks.

[341] As discussed in Chapter 5.3.4, intrapreneurs/entrepreneurs are associated with team building skills and the creative capacity to involve good people (Ref. Pinchot, 1985)

To deal with the problem of lacking standardized methods of analysis for omega-3 fatty acids, Breivik arranged "Analysis Meetings" and inter-laboratory tests. He believed that the orchestration of a close collaboration between experts in the field could influence the issue. At the "Analysis Meetings," specialists on the analysis of marine oils and omega-3 fatty acids discussed and compared the different methods being used in order to develop procedures as similar as possible. Breivik also made contact with several laboratories worldwide to engage them in round-robin tests. These studies were followed by visits to laboratories where Breivik and his co-workers assessed the results and relevant competence issues.[342] The work forms in question contributed positively to the development of official standardized methods for analysis of omega-3 fatty acids. Not only that, Breivik and his colleagues developed methods that were published in one of the leading US journals in the field and approved by a European expert group. This achievement contributed to giving them the appreciation as internationally recognized specialist in the field of omega-3 research. Thus, Breivik's know-who was important.

Breivik's successful design of appropriate work forms illustrates that *know-who* includes far more than information on relevant experts. Know-who is also about *knowing how* to orchestrate a fruitful collaboration with the experts in question.[343] In this connection, Breivik's approach suggests that the facilitation of *co-generative learning processes*[344] based on repeated cycles of collective reflection and action is essential.[345] This, in turn, reflects Philips' (1988) finding that the capacity to arrange and participate in joint reflection and learning is a hallmark of successful *souls of fire*.[346] Accordingly, it is appropriate to say that Breivik actively promoted innovation by means of his role as a *co-generative learning booster* and that this role embodied a vital part of his *know-who*.

Moreover, Breivik's emphasis on establishing contacts with external experts provided himself with considerable power of influence in terms of social capital. Clearly, if it were not for his social capital, the project team would probably not have succeeded with critical project tasks. The patent application process in the US and the adoption of Hydro's analysis method as an official method, are prominent examples here.

[342] The Hydro researchers themselves were also invited to take part in such studies. According to a project member, these invitations indicated that the Hydro researchers' work on omega-3 fatty acids was internationally recognized.
[343] As previously discussed, know-who involves the formation of special social relationships with the expertise involved that makes it possible to get access to and use their knowledge efficiently (Foray and Lundvall, 1996).
[344] Ref. Greenwood and Levin (1998)
[345] I make a further discussion of appropriate work forms in Chapter 9.4.
[346] The souls of fire are individual key actors deeply involved in work organization development projects who have an important impact on the development and viability of the new organizational solutions (Ref. Chapter 5.3.5).

When the US patent authorities opposed the k85 patent[347], supportive statements from the professor at the Canadian Institute for Fisheries Technology and the American Department of Commerce proved to be decisive for the approval of the patent.[348] Similarly, one of Breivik's fellows in "The Group of Experts for Fatty Oils and Derivatives for the European Pharmacopoeia Commission" had a decisive influence on the outcome of a controversy concerning Hydro researchers' work on methods for analyzing omega-3 concentrates. The expert, representing his country, was acquainted with Breivik and his Hydro colleagues. He knew their work was solid, and he verified their work. This verification implied that the objections were withdrawn. Breivik told:

> *…I remember once when Country A vetoed an issue we were working on. That was an unusual thing to do. But country A had shown a fair amount of protectionism in order to arrange things in a different way to protect their industry…The expert from country B agreed with us. Country C had not yet made up their mind.* ***In this and similar cases, the ability to convince the group members how the facts really are, is very important****…When the case was being discussed at a higher level, the representatives from country A had criticized the work that had been done. However, at the next meeting the leader of the delegation (from country C) returned, saying that "Our expert has read what the Norwegian specialist has written, and everything is verified." In reality that caused the veto to be dropped. Thus, one might say, then, that there were cases when solid knowledge triumphover protectionism. But, it is quite a difficult thing to accomplish, because you have to be able to convince other team members.* ***If we did not have this point of contact, if the expert from country C did not know who we were, I think this would not have been the result. I think it would not have happened, if there had been only a comment on a piece of paper of which you didn't know the author…****One should add that later we have obtained a good working relationship with the representatives of country A.* (Emphasis is mine)

Thus, this example shows that Breivik's professional expertise was necessary, but not sufficient to convince the expert group about the virtue of his contribution. His capacity to enlist the necessary support also relied on his social capital.

The Vice President of the Hydro Agriculture Business Unit, heading the areas of fish farming and fish feed in the period 1986 through 1990, is the final member of the Omacor™ project whose contribution will be outlined here.

The Vice President had a master's degree in agriculture and had previously headed a large fish meal company. As such, he was familiar with research on fatty acids and the fish oil and fish feed industries. The Vice President had a large international network, and he

[347] Ref. Chapter 6.6
[348] This case is further outlined in Chapter 12.6.3

has been characterized as a dynamic and people-oriented person.[349] He often made contact across organizational lines, asking for meetings and inviting people to talk about their work. As the new head of the fish farming and fish feed activities, the Vice President was interested in exploring new opportunities within the field of biotechnology. The Vice President found the Omacor™ project highly interesting, not least in light of the prospect for synergy with other marine activities. Based on his trade knowledge, he argued in favor of using commercial fish oil rather than fish waste for the production of an omega-3 medicine. In addition, he saw the opportunity for making fish oil a new area of business for Hydro. The Vice President's point of view strongly influenced Hydro's decision to acquire two Norwegian fish oil companies that happened to be for sale in 1987/1988. These purchases represented a turning point in the Omacor™ project. The fish oil companies provided access to high-quality fish oil, production technology, and competence, and turned Hydro into one of the leading fish oil companies worldwide. According to project members, the Vice President played a decisive role in transforming the initial explorative project efforts into a considerable project influencing the overall interest for omega-3 activities in Norway. Emphasizing the importance of the Vice President's trade knowledge, one of the project members commented:

> *…He knew what fish oil was like as a commodity, he knew procedures, he knew what was up for sale. He had been dealing with fish feed and fish oil for a long time...He was familiar with quality standards, standard raw material, and standard processes and volume...He knew that in order to turn fish oil into an industrial business area, the natural thing was to buy a company representing this area…* ***It is a huge difference between knowing an industry and imagining what is happening there****…*(emphasis is mine)

Evidently, the Vice President acted as a *promotor of power*, actively and intensively promoting the Omacor™ project by means of his hierarchic power.[350] In addition, his *context-relevant skills* in terms of relevant trade knowledge regarding the fish oil industry were important, making him a *promotor of know-how*. As such, power by virtue of

[349] Svendsen (1996)
[350] Ref. Witte (1977)

hierarchic power and context-relevant skills are salient characteristics of his contribution to the Omacor™ project.[351]

In sum, the presentation of the three project members of the Omacor™ project calls attention to *domain-relevant skills*, *context-relevant skills*, *know-who*, *power by virtue of political skills, power by virtue of formal authority,* and *power by virtue of social capital* as salient characteristics of individual contributions promoting innovation in this project. In addition, the analysis of the individual contributions indicates that context-relevant skills, political skills, and social capital underlie the role as *product champion*, while individual know-who is embedded in the roles as *strategic networker* and *co-generative learning booster.*

PROSMAT Extrusion. Subproject 1: Long Die Life for Hard Alloys

I now call attention to *Sigurd Rystad*, the subproject manager of PROSMAT Extrusion Subproject 1: Long Die Life for Hard Alloys (hereafter called the "Die Life" project for short).

The "Die Life" project was a continuation of research activities in the foregoing EXPOMAT program and in-house Raufoss Automotive projects directed at increasing die life of AA 7000 alloys.[352] Due to customer demands, Raufoss Automotive had started the production of thin-walled hollow AA7000 profiles in the late 1980s. Extrusion of such profiles led to severe technical problems resulting in "catastrophically" short die life for hollow dies. Increased competition from the steel industry meant that Raufoss Automotive had to solve the problem in order to survive as a manufacturer of hollow aluminum bumpers. Through the EXPOMAT period, important results were obtained, contributing to a considerable increase in die life. Still, an additional doubling of lifetime was seen as necessary to compete with bumpers made of high-strength steel. For this reason, the development of the next generation of extrusion dies for hollow AA7000 profiles became the objective of the "Die Life" project.

Sigurd Rystad, the manager of the EXPOMAT "Die Life" project and the in-house project was regarded as a clear candidate for the position as the subproject manager. He had a master's degree in physical metallurgy and had been with Raufoss Automotive (later

[351] Obviously, since the Vice President had a large international network, he also had a strong power of influence in terms of *social capital*. In addition, I suggest that he positively influenced the Omacor™ by means of his interpersonal skills. However, in the current description I have chosen to highlight his hierarchic power and context-relevant skills only since I have no further information concerning the other characteristics just referred to.

[352] AA7000 alloys are a series of high-strength aluminum alloys (Ref. 6.1.2).

Hydro) since 1976. During these years Rystad had been involved in a variety of work tasks ranging from management positions in the press plant to R&D activities at the local research center.

Rystad's orchestration of a strong interdisciplinary, inter-organizational interplay of researchers and industrial people was vital for solving the die life problems. Similar to Harald Breivik in the Omacor™ project, he promoted innovation by means of his *know-who* embodied in the roles as *strategic networker* and *co-generative learning booster*. I illustrate this by showing how his emphasis on a parallel processing strategy and the arrangement of brainstorming sessions enabled the birth of the New Die, the successful new die concept.

To deal with the die life problem, Rystad concluded that the acute situation required a multiple strategy in which several ideas were tested in parallel. According to him, parallel processing would be far more effective than the conventional linear approaches. In addition, Rystad emphasized the importance of involving both external research groups and local people in the project. As such, the multiple-strategy implied that the researchers and industrial workers would approach the die life problem in parallel. Rystad made contact with SINTEF Materials Technology where he had a network of acquaintances as a result of his master's degree studies, his engagement as a research assistant, and his participation in several SINTEF projects over the years. He hired material technologists to study "damaged" dies to find out where and why cracks appeared. At the same time, Rystad engaged researchers at SINTEF Industrial Mathematics to do numerical simulations, in particular stress computations to find out if new die designs could reduce stress in critical areas of the dies. Rystad also established an in-house project team. The project team, collaborating closely with the steel manufacturer, focused on maintenance procedures for dies and issues concerning steel quality and extrusion process management.

The SINTEF researchers contributed with valuable input in terms of suggestions for proper die design. In parallel, the local project team tested and verified the researchers' hypotheses through practical testing, offering valuable information directing the further theoretical work. Rystad supported the interplay of the external researchers and local people through his action-minded approach that boosted learning and enabled rapid results. In the words of a project member:

> *…His boldness, his willingness to take action, to take a chance through practical tests in normal production, created rapid results. Even though not all tests revealed*

> *positive results, this approach was important: Whenever you fail, you learn a lot. If the errors are not brought into light, no one has the chance to learn…*

Within a short time, the joint efforts revealed that the die design at that time had reached its limit with respect to die life; further optimization was not possible. Accordingly, a new die design was needed to avoid the cracking problem.

Facing this great challenge, Rystad decided to arrange a large brainstorming meeting to generate ideas for a new die concept.[353] He emphasized the importance of inviting people covering a great variety of theoretical and practical competence. So, along with the formal project members, Rystad invited several other people, for instance representatives from the steel manufacturer, the tool manufacturer, Hydro Extrusion, and the Research Center at Karmøy. He also invited Hydro Automotive staff members working on other forming processes, thereby thinking beyond the specific context of extrusion.

The brainstorming meeting resulted in a number of principally different die designs. The ideas were evaluated through numerical simulations, and further testing revealed that the New Die appeared to be the most promising concept regarding reduction of stress in critical areas ("hot spot stress"). This concept was proposed by a person working on another aluminum forming process within Hydro Automotive. Similar to aluminum extrusion, this particular process involved the use of dies, putting strong demands on die design. Rystad's emphasis on inviting staff members "outside" the field of extrusion thus brought this particular principle into focus. A project member attributed this favorable link to Rystad's knowledge of diverse Automotive business activities; the project manager did not involve "outsiders" randomly:

> *…A person entering from the outside would hardly have been able to see that link. Of course, there is still the possibility that the actual design might have appeared through other ways. You never know for sure. However, without the detailed knowledge of local conditions, you would not have managed to make this connection…*

In other words, Rystad's *know-who*, including his capacity to involve good people and design work forms fostering collective reflection and action, was important.

Apart from acting as a *strategic networker* and *co-generative learning booster*, Rystad positively influenced the success of the Die Life project through his *power by virtue of social capital* and *communication skills*.

[353] Minutes of Meeting. Meeting 1996-21-10; 1996-12-03.

Rystad's power by virtue of social capital contributed to a remarkably close interplay between research and operational work. His previous management positions provided him with a strong informal authority, enabling him to effortlessly pass formal lines or usual barriers. For instance, his authority made possible the achievement of practical testing and implementation of research results. A project member explained:

> *… A common problem related to the implementation of research results is a lack of commitment from managers in the press plants. The unique thing about Sigurd Rystad was the fact that he had previously held the position of manufacturing manager. As a consequence,* ***he had the authority to go straight into the plant and have things done.*** *And things were really done. In this way, one got feedback from test runs, implying a fantastic integration of research and operational work that is not found anywhere else within the Hydro system…*(emphasis is mine)

Supporting this statement, another project member commented:

> *…The fact is that Sigurd had many years of experience from the press plant. He had held several management positions...Therefore, he was really not dependent on people in the press plant to run tests. He just ordered, you know: OK, now we make such a die!…*

Finally, Rystad's communication skills by virtue of his ability to "speak the language" of both researchers and industrial workers was important. It made him an ideal node, reducing the traditional gap between these groups. As a project member explained:

> *…Having a man like Sigurd Rystad in the project was very important because there tends to be a distance between those working with the theory and those who have the actual needs. In this project – well, there will always be some distance – but here the distance was smaller than it could have been…*

In sum, the examples above show that *power by virtue of social capital*, *communication skills,* and *know-how* embodied in the roles as *strategic networker* and *co-generative learning booster* were salient characteristics of Sigurd Rystad's contribution to the "Die Life" project.

PROSMAT Extrusion. Subproject 2: Modeling of Flow in the Bearing Channel

In the following I present *Trond Aukrust*, the subproject manager of PROSMAT Extrusion. Subproject 2: Modeling of Flow in the Bearing Channel (hereafter named the "Bearing Channel" project for short). I also briefly highlight how *Mari Wilhelmsen*, the project manager of an in-house Hydro project, and a top manager in Hydro Extrusion positively influenced the Bearing Channel project.

The aim of the "Bearing Channel" project was to develop proper FEM models[354] that could provide a better understanding of the mechanisms taking place inside a die during extrusion. The foregoing EXPOMAT projects resulted in 2D and 3D FEM models able to describe the extrusion process *up to* the point where a section leaves the die. Still, these models could not provide a satisfactory description of the *bearing channel*, i.e. the surface along which the aluminum flows and is shaped (see Figure 8.2.1). As a consequence, predictions of a section's movement after the outlet, that is, if it moves straight on or turns away from its original course, could not be made. The researchers knew that improper geometrical conditions in the bearing channel might lead to improper flow balance that, in turn, would create defects that possibly failed to meet essential quality demands for extruded sections.

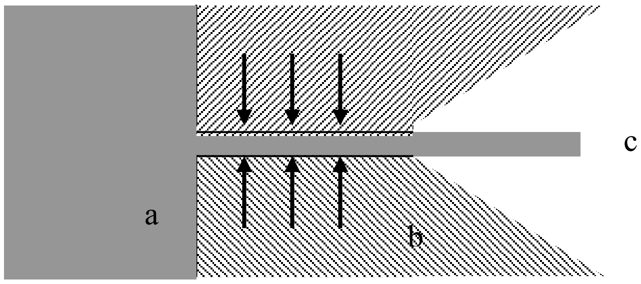

Figure 8.2.1 The Bearing Channel (a: Billet; b: Die; c: Extruded Profile)

For this reason, modeling of flow in the bearing channel was important to make Hydro Extrusion capable of meeting the ever-increasing demands for tighter geometrical tolerances and better surface quality.

Discussions on industrial needs in the pre-project soon brought surface quality into focus. Surface appearance was of major importance for the building sector, the largest market for HA.[355] Visible defects often meant costly complaints and new deliveries. At the same time, the mechanisms for several common surface defects were not well known, meaning knowledge on how to make appropriate changes to reduce defects was scarce. Therefore, the subproject manager *Trond Aukrust* recommended that the project should aim at a deeper understanding of the mechanisms for surface defects and the development of

[354] FEM models are mathematical models based on the Finite Element Method (FEM), ref. Chapter 6.1.4

[355] New Modelling Techniques for the Future Extrusion Technology. Modelling of Properties. Pre-Study Report May, 1996.

FEM models for these phenomena. In turn, this understanding could provide knowledge of how to avoid these surface defects.

Trond Aukrust worked at SINTEF Materials Technology in Oslo. He had a doctoral degree in statistical mechanics and had many years of experience with large-scale numerical simulations from IBM and SINTEF. Among other things, he had been involved in a preceding EXPOMAT project dealing with surface quality on extruded sections. As the subproject manager of the "Bearing Channel" project Aukrust suggested that the project should start with a careful characterization and study of surface defects in order to be able to propose hypotheses for mechanisms leading to the surface defects in question.[356] The hypotheses were to form the basis for the development of FEM models able to simulate and predict flow in the bearing channel. In turn, such models would provide knowledge enabling the preparation of recommendations of how to avoid surface defects.

During the project Aukrust was involved in experimental die studies and the theoretical work aimed at developing adequate simulations of flow in the bearing channel. He also spent much time at various press plant, discussing industrial needs and problems with local workers and taking part in full-scale experiments and verification efforts. All together, the experimental and theoretical work contributed to a deeper understanding of the mechanisms of surface defects. The new understanding resulted in recommendations and guidelines for the design and maintenance of dies. In this connection, project members call attention to Aukrust's "path-breaking" 2D FEM model. By means of this model, he managed to perform detailed 2D analyses that were able to explain known effects of various design and correction strategies. The 2D simulations also led to new insight and understanding of how flow in the bearing channel and interactions between the bearing surface and the section surface influenced surface quality and geometrical deflections. The obtainment of these results is recognized as a major event of the project. In particular, project members point out the strong pedagogical power of Aukrust's model; it represented a breakthrough in communicating and explaining flow in the bearing channel. As one of them explained:

> *… From a research point of view, I think Trond's development of the 2D model for flow in the die, providing a physical description of what happened when we extruded… was the major event of the project. We had run practical experiments. We had dissected a die. However, he managed to develop a model that described what happened in an effortless way. The model made communication about these things easy…To me, this way of explaining a problem was a breakthrough…*

[356] New Modeling Techniques for the Future Extrusion Technology. Modelling of Properties. Pre-Study Report May, 1996.

Aukrust himself said:

> *…The 2D model was important, because I know people with many years of experience from extrusion, for instance the manager of the Dies Fit For Use project. He had worked with dies for many years. According to him, the 2D model made him understand 50 or 80% of what he previously did not understand about die design…*

Aukrust's successful development of the 2D FEM model was enabled by his high level of *domain-relevant skills*, *context-relevant skills* in terms of knowledge of the extrusion process and local conditions in HAEX, and his strong *interpersonal* skills. Clearly, Aukrust's domain-relevant skills in terms of his expertise on mathematical modeling techniques were important for obtaining new knowledge of flow in the bearing channel. According to project members, Aukrust is a researcher with a high proficiency: "*He has repeatedly demonstrated that he is possibly the best person in this country to do these simulations*!" a project member stated. Another project member credited Aukrust for the development of the hypotheses for surface generation:

> *…It's quite clear that one good researcher was the main cause…Of course, there may be thousands of other small reasons that are difficult to point out. Nevertheless, the driving force was linked to one particular person...We had never achieved the results without him. That's an absolute certainty…*

Reflecting on his professional competence, Aukrust himself considered his broad experience with modeling and ability to catch the fundamental understanding of phenomena as his major strengths:

> *…I have a very broad experience with modeling… Besides, the ability to intuitively grasp how things work – the mechanisms – is a strong point of mine… Without this kind of understanding there is no point in initiating large modeling efforts. You get lost in numerics and large amounts of data with little chance of extracting the fundamental understanding. On the other hand, if you understand a problem, or have a good working hypothesis, you know how to solve it. Then you may model things in a relatively simple way and display the main mechanisms. I think that's a strong point of mine …*

Aukrust's statement indicates that his expertise on mathematical modeling techniques was necessary, but not sufficient for developing the 2D FEM model: His achievement also relied on his understanding of the extrusion process and local industrial conditions, that is, *context-relevant skills*. The extrusion process is known as one of the most difficult cases for numerical simulations.[357] Therefore, reliable simulations presuppose a broad expertise on modeling, including fundamental process knowledge. In the words of a project member: "*Understanding and knowledge of the very extrusion process is essential when doing numerical simulations. You definitely have to understand the process*!"

Visits to extrusion plants and dialogues with local experts helped Aukrust and his co-workers to acquire important context-relevant skills. Emphasizing the importance of such skills he recounted:

> *…Getting first-hand experience with the process and observing what works and what does not work, is really useful. Pure thinking in your office is simply not enough.* ***The contact with the industrial projects was decisive for the outcome of PROSMAT, because of the knowledge or competence you acquire by being out in the plants, observing what's going on****. For instance, you get a thorough understanding of the process and the die technology, and you learn about bottle necks and things at the heart of the process that are decisive for achieving the desired quality…*

Aukrust developed his knowledge of the extrusion process and local industrial conditions through his continuous involvement in Hydro Extrusion projects from 1993 onwards.[358] In this connection, the impact of his *interpersonal skills* is noteworthy. Aukrust's capacity to communicate well with industrial people, including his ability to catch and tune into the needs of industrial clients, facilitated his acquisition of context-relevant skills. Not only that, Aukrust's interpersonal skills were decisive for accomplishing critical project tasks such as full-scale extrusion experiments at the press plants. According to several project members, Aukrust and his teammates were "the right sort of people" for collaboration with industrial partners. As one of them explained:

> *…The choice of people is critical, that is, not everyone can be sent out to such an organization. The people have to have some experience - or have to be strongly supported by someone who has such experience. They need to communicate well with the shop floor people. Simultaneously, they must have the ability to work systematically and make something out of the information they manage to collect...If*

[357] Ref. Chapter 6.1.4

[358] During the PROSMAT project, people in Hydro Extrusion became increasingly aware of the value of the particular combination of "first-hand process knowledge" and "a more scientific approach to the problems," as one of the project members put it. As a result, the subproject manager and some of his colleagues have since been invited to take part in Hydro's own processes directed at defining visions and overall targets for projects.

> *you send a theorist who… scatters academic terms no one understands, then you won't get far in that world…*

Supporting this statement, another project member claimed:

> *…All the time, successful accomplishment of projects like PROSMAT relies heavily on the quality of the interchange and interplay between researchers and operators…*

More specifically, Aukrust's capacity to communicate well with and learn from press plant workers was decisive for creating local commitment and interest in defining and solving critical project tasks. In turn, access to "good pilot plants with enthusiastic people who support the project," as a project member expressed himself, was necessary for carrying out full-scale extrusion experiments. As Aukrust recounted:

> *…We traveled around to talk with people to get to know their understanding of the matter. Next, when we had discovered some things ourselves, we went back to present our understanding of things along with suggestions for methods of solution. When they saw the potential benefit, and realized that our efforts could result in improvements, they became fully committed to our project…Thus,* ***without their understanding of our propositions or their recognition of the practical value, they would not have been willing to cooperate****…Our interest in solving their problems was met with an open attitude facilitating the accomplishment of practical experiments and manufacturing of test dies and such things… This goodwill was quite decisive…****Without it, things just stop****…* (emphasis is mine)

In particular, the commitment from local managers was vital. As another project member explained:

> *…The managers I worked with took a great interest in the project. Without their commitment, success had not been possible. You have to have the management on your side. An organization like that does not work unless the managers say: This is how things should be! They have to take a real interest in the problem...*

Clearly, Aukrust's interpersonal skills in terms of communication skills and client-orientation positively influenced innovation success in the "Bearing Channel" project. The concepts *empathy* and *social skill* appear to be fruitful terms capturing the essence of Aukrust's interpersonal skills.

Empathy and social skills are both components of emotional intelligence and concern a person's ability to manage relationships with others (Goleman, 2001). *Empathy* includes the ability to manage meaningful relationships, the capacity to build networks, and skill in treating people to emotional reactions. For instance, service to clients and customers, reflected in Aukrust's client focus, is a hallmark of empathy. *Social skill* is about proficiency in managing relationships and building networks and the ability to find common ground and support. The hallmarks of social skill are effectiveness in leading change, persuasiveness, and expertise in building and leading teams (ibid.). Most probably, Aukrust would not have succeeded in creating the commitment and goodwill necessary for carrying out evaluation and implementation efforts without his empathy and social skill.

To summarize, Aukrust' high levels of *domain-relevant skills*, *context-relevant skills* and *interpersonal skills* embodied in *empathy* and *social skill* were salient characteristics promoting innovation in the Bearing Channel project.

The "Bearing Channel" project was closely connected to two in-house Hydro projects. I now briefly indicate how *Mari Wilhelmsen*, heading one of these projects, promoted innovation through her *power by virtue of social capital*.

Wilhelmsen had a master's degree in metallurgy and about ten years of experience from the R&D center at Karmøy and SINTEF Materials Technology. She had also worked about one and a half years as a front line researcher at a Hydro press plant in Italy. During PROSMAT she was employed at SINTEF Materials Technology, working on Hydro projects. Due to her long engagement in Hydro projects she had a wide range of acquaintances in Hydro Aluminium, including national as well as foreign groups. Wilhelmsen's personal network in the field made possible easy access to pilot plants and practical testing of importance for the "Bearing Channel" project and the Hydro projects. In the words of Wilhelmsen:

> *…Having a project leader who already knew most of the groups, having many acquaintances both upwards and downwards in the organization was beneficial. It contributes to the matter – opens some doors – and maybe closes some as well. It was definitely no disadvantage…*

Furthermore, the former HAEX client representative in PROSMAT Extrusion, who entered a top manager position at HAEX's head office a short time after the PROSMAT program was initiated, provides an example of the significance of a *promotor of power*, i.e. power by virtue of formal authority. This top manager actively supported the emphasis on a close continuous interaction between researchers and industrial people, thereby facilitating the implementation of recommendations for die maintenance and die design in HAEX plants. A project member explained:

> *…To gain access to the Hydro system, the support of the head office in Lausanne acting as a driving force in the project was important. Without their support, things would have been a lot more difficult…I think it all started with [name of the former HAEX client representative], who…after a short time became technical manager in Lausanne. He was the father of it, taking a burning interest in this way of working…**I think that if it wasn't for him, the progress would have been a lot slower, because as a representative of Lausanne he a decisive power of influence: The word of Lausanne is the law! ...*** (emphasis is mine)

Accordingly, the brief presentations above show that both formal power and informal power by virtue of social capital are salient characteristics of individual contributions promoting the "Bearing Channel" project.

PROSMAT Extrusion. Subproject 3: Empirical Modeling

Tom Kavli, the subproject manager of PROSMAT Extrusion. Subproject 3: Empirical Modeling (hereafter called the "Empirical Modeling" project for short), is the final person whose individual contribution will be presented in this chapter.

The "Empirical Modeling" project was based on the idea of utilizing process data logged at extrusion presses to predict and optimize process parameters and thereby obtain better process control and productivity.[359] During the former EXPOMAT program, the main project manager of EXPOMAT Extrusion regularly discussed ideas with one of the managers in Hydro Aluminium Extrusion. Among other things, they reflected on the observation that huge amounts of empirical process data were generated during press runs and then stored in process databases without being made further use of. This recognition triggered the questions: "Is it possible to use this data in a smart way?" "Could the process information stored in databases and files for CAD drawings be used to learn about the process?" The Hydro managers discussed the idea with several people, among those a SINTEF researcher who was engaged with EXPOMAT. They learned that the SINTEF researcher, due to the joint location of several SINTEF departments in Oslo, was acquainted with colleagues working on empirical modeling methods. The SINTEF researcher offered to introduce the idea to these people.

[359] Empirical modeling is about modeling the relationship between parameters grounded in analysis and interpretation of empirical data.

Tom Kavli and his colleagues found the idea highly interesting. During the project they managed to develop software tools based on empirical models that, among other things, could predict press speed for new sections. These software tools, the so-called Speed Predictor and Shape Finder, are seen as radically new products within Hydro Extrusion, representing "major steps forwards to the current state of the art in industry."[360] Similarly, the software tools are regarded as radical innovations in the scientific world.

Tom Kavli contributed strongly to this successful outcome through his *domain-relevant skills*, *context-relevant skills*, and *interpersonal skills* in terms of *empathy* and *social skill.* He had been in SINTEF for about 15 years, having a good record from previous projects. Kavli had a master's and doctoral degree in physics and computer science respectively, and he had been working in the fields of instrumentation, measurement techniques, data analysis, and statistics. Clearly, his professional expertise in physics and computer science was decisive for the development of the empirical models underlying the software tools in question. The main project manager of PROSMAT Extrusion argued:

> *…We had not managed to do any of this if it wasn't for the expertise Kavli and his colleagues represented. That's really alpha and omega for initiating a project within a new area. If you don't have it, the only alternative is to stop…*

In addition, the project manager called attention to the significance of Kavli's experience with industrial projects:

> *…We had a dynamic, competent project manager in SINTEF who had both the pure academic expertise, as well as broad industrial experience. He was the right person!...*

Elaborating on this, the project manager said:

> *…He has worked lot with several different industrial problems. Besides, he is really good at understanding the core of the problems, and to communicate and make use of feedback from the final users of the product. I think that was very important here...*

The latter statement gives a clue about salient characteristics of Kavli's overall contribution to the "Empirical Modeling" project. Apart from being an academic of high standing, Kavli is a man capable of establishing good relationships with industrial people. His

[360] PROSMAT: New Modelling Techniques for the Future Extrusion Technology. Project report, 1999.

communicative skills, capacity to learn from discussions with press plant workers, and his strong client orientation, that is, his attention to client needs rather than personal interests, appear as important conditions enabling the fruitful research-industry interplay obtained in the “Bearing Channel” project. In turn, this interplay was decisive for the development of reliable empirical models and thus appropriate software tools for better process management. I now illustrate how Kavli promoted the “Bearing Channel” project by giving a brief outline of activities and incidents in the project.

The project started with a six-month pre-project aimed at finding proper ideas for practical application of empirical modeling techniques in Hydro Aluminium Extrusion. During the pre-study Kavli and his teammates emphasized the importance of visiting several extrusion plants, tool manufacturers, software suppliers, and research groups to discuss the project idea. Based on the impressions from the visits and the discussions, Kavli prepared a pre-study report including a presentation of major project ideas, reflections on where research should be focused to gain improvements, and an evaluation and recommendation of project ideas.[361] The idea named “Analysis of Production Data and Dependencies on Profile Shape” was regarded as the most promising, and Kavli proposed the start-up of a main project based on this idea. Still, further discussions were needed to make decisions about specific applications, and Kavli went on, discussing possible applications with industrial people and academic research groups.

Kavli and his colleagues spent considerable time at press plants, establishing contact with people at various levels to learn about day-to-day practices and topics of industrial interest. Through these collaborative discussions, prediction of press speed for new sections emerged as the main theme. Kavli’s client focus and emphasis on learning about industrial needs and problems by spending time at local sites, is seen as a prerequisite for successful implementation of research results in general. As a member of the steering committee commented:

> *…The fact that they entered the press plants, observing what actually happened, was a very important aspect of that project… Implementation of research that does not take this into account is likely to fail… The actual operation of day-to-day production has to be the basis for the research…*

[361] SINTEF REPORT No STF 72 F 96 618 1995-12-13 (restricted) New Modeling Techniques for the Future Extrusion Technology Empirical Modeling. Pre-Study Report.

During the first year and a half, Kavli and his colleagues collected process data from three extrusion plants. In parallel, they started developing software for efficient analysis of these data. In the early phase they also noticed that the geometry of sections and dies was an important input to empirical models. In order to do statistical analysis and modeling of process data, Kavli and his teammates thus needed to be able to relate the process data to section shapes.[362] At the same time, the great number of different sections and corresponding CAD drawings[363] necessitated the development of an automatic means (algorithms) for analysis and interpretation of CAD drawings.[364]

When Kavli and his teammates carried out analyses based on the early versions of the software for process and shape analysis, the results revealed large speed variations in the same die at all extrusion plants. These variations made the data less suitable for developing empirical models able to estimate process parameters and productivity for new sections. The way Kavli approached this situation provides another example of his emphasis on industrial input and exchange of experience with local workers.

To identify the reasons for the variations, Kavli and his colleagues arranged a large meeting at the press plant at Karmøy. They presented and discussed their findings with, among others, all the press operators responsible for setting the process control parameters. The press operators recognized the variations, providing several explanations for the situations without being able to give a sound answer to the problem. Based on this response, Kavli recommended the initiation of an in-house HAEX project to work on the problem. At the same time, he and his colleagues concluded that the available process data and CAD drawings were not sufficient for building empirical models. They realized that they also had to make use of the operators' practical knowledge and experience.

In the spring of 1998 prototypes were ready for presentation and demonstration at several extrusion plants. The tools were met with great interest and enthusiasm, encouraging the further development of the tools into evaluation versions. The successful realization and demonstration of the initial project idea into these products is regarded as a significant event in the project. According to project members, the user-oriented attitude Kavli and his colleagues expressed is a main reason for why the model prototypes were very well received at the press plants. One of them said:

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[362] SINTEF report no STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.
[363] CAD is the abbreviation of Computer-Aided Design.
[364] A plant typically produces several thousand different section shapes.

> *…One important reason for this is a proper understanding and recognition of the operational problems, putting these problems, not personal research interests, into focus…*

Similarly, several project members point out that Kavli's user orientation was decisive for creating commitment to the project at the press plants. This commitment facilitated access to pilot plants enabling evaluation and implementation projects. In turn, the evaluation/implementation efforts, encouraging a close communication between industrial people and SINTEF researchers, provided important knowledge necessary to improve the empirical models and develop the evaluation prototypes in "the right direction", as Kavli expressed himself.

Thus, apart from Kavli's *domain-relevant* and *context-relevant skills*, interpersonal skills in terms of *empathy* and *social skill* were salient characteristics of his positive contribution to the "Empirical Modeling" project.

8.2.2 Final Summary Discussion

The foregoing presentation calls attention to the following salient characteristics of individual contributions promoting innovation: *political skills*, *communication skills*, *power by virtue of social capital*, *power by virtue of formal authority*, *social skill*, *empathy*, *know-who*, *domain-relevant skills*, and *context-relevant skills*. In sum, these characteristics reflect two striking findings concerning necessary components of individual creativity: First, *interpersonal skills are essential for individual creativity*.[365] Second, *context-relevant skills*, i.e. relevant knowledge of the problem context and required technical skills, *are vital for making creative contributions in innovation projects*.

When I compare the portraits outlined in Chapter 8.2.1, I observe that interpersonal skills were a prominent part of *all* individual contributions promoting innovation. Indeed, most people presented were persons acting in the dual role as a researcher and project manager. Therefore, the observation that project managers display interpersonal skills is not surprising; I simply expect it! Still, the finding that interpersonal skills were generally important for innovation success is noteworthy. The finding suggests that the common idea of asocial inventors and social "innovation promotors" is wrong (Ref. Chapter 5.3.6). As

[365] In this thesis I simply use "*interpersonal skills*" as a collective term comprising *political skills*, *communication skills*, *power by virtue of social capital*, *power by virtue of formal authority*, *social skill*, *empathy*, and *know-who*.

such, it represents an appropriate corrective to most creativity research that reflects the mistaken belief that interpersonal skills are irrelevant to creative performance. More specifically, my study of individual contributions in the case projects provides a powerful corrective by virtue of illustrating *how* various types of interpersonal skills influence creativity.

First, my study shows that the individual capacity to convince significant others about the virtue of the novelty one has produced is vital (Ref. Csikszentmihalyi, 1999). For instance, Børretzen's *political skills* and his active and intense promotion of the Omacor™ project through his *product champion* role was critical for gaining support from top management. Likely, if it were not for this support, his project idea would not have become a reality. Similarly, if it were not for Breivik's *power by virtue of social capital*, his novel contribution regarding methods of analysis would not have been accepted by the expert group in question (*"In this and similar cases, the ability to convince the group members how the facts really are, is very important"*).

Second, my study points up that the significance of interpersonal skills exceeds their specific role in the work aimed at gaining social acceptance for novel contributions. For instance, Trond Aukrust's *empathy* and *social skill* facilitated his acquisition of context-relevant skills enabling his development of the 2D FEM model of flow in the bearing channel. At the same time, it is evident that Trond Aukrust's interpersonal skills also promoted innovation in terms of supporting the project team's *collective* capacity to define and solve open-ended problems. Possibly, Aukrust would not have succeeded in creating the commitment and goodwill necessary for carrying out industrial full-scale experiments if it were not for his empathy, social skill, and capacity to communicate well with industrial people. This is also the case with Kavli in the "Empirical Modeling" project. In other words, the subproject managers' interpersonal skills enabled the accomplishment of a critical project task. The industrial experimental work, in turn, provided the researchers with vital knowledge facilitating their individual capacity to make a creative contribution to the project.

In a similar way, the other contributions outlined exemplify how individual interpersonal skills facilitated both individual and collective creativity. Persons with *power by virtue of formal authority* or *power by virtue of social capital* managed to provide access to critical resources (e.g. pilot plants) and made the project team achieve desired ends (testing, implementation) with a lot less effort than would otherwise have been the case. For instance, the HAEX top manager promoted implementation in the "Bearing Channel" project *("The word of Lausanne is the law")* and Sigurd Rystad heading the "Die Life" project "had the authority to go straight into the plant and have things done". Furthermore, Harald Breivik and Sigurd Rystad, acting in the roles as *strategic networker* and *co-generative learning booster*, illustrate the importance of *know-who*. Likely, if it were not for the project managers' capacity to involve relevant specialists and orchestrate a fruitful collaboration between local project members and external experts, neither the Omacor™ project nor the Die Life project would have succeeded.

So, to summarize, my study shows that *interpersonal skills such as political skills, communication skills, power by virtue of social capital, power by virtue of formal authority, social skill, empathy, and know-who are vital for individual as well as for collective creativity*. Interpersonal skills enable the obtainment of critical support from significant others, encourage the development of context-relevant skills, make access to important tangible resources easier, provide access to necessary expertise, and, finally, encourage a well-functioning interplay of people in innovation projects by facilitating adequate collective learning processes. *I therefore argue that interpersonal skills should be considered as a component of individual creativity*.[366]

Apart from interpersonal skills, *domain-relevant* and *context-relevant* skills are salient characteristics of individual contributions promoting innovation in the case projects.[367]

My analysis of the individual contributions shows that domain-relevant skills in terms of disciplinary knowledge are important for individual creative performance. For instance, Trond Aukrust's expertise on mathematical modelling and Harald Breivik's expertise on the analysis on organic compounds were necessary for their capacity to deal with critical

[366] In this connection, I find that Goleman (2001) provides further support for my conclusion. Studying ingredients of outstanding leader performance, Goleman (2001) found that *emotional intelligence* (of which *empathy* and *social skill* are two components) proved to be twice as important as technical skills and IQ for jobs at all levels. He reports that other researchers have confirmed that emotional intelligence not only distinguishes outstanding leaders, but can also be linked to strong performance. Accordingly, skills shown to be twice as important as technical skills in outstanding leadership performance appear as a natural component of creative performance as well. For instance, Barrett (1998) points up that emphatic competence is necessary for a successful jazz performance.

[367] When I view this finding in light of Amabile's (1983a/b; 1988; 1996) attention to *domain-relevant skills*, *creativity-relevant skills*, and *task motivation*, it is evident that my data calls attention to skills pertaining to the component "domain-relevant" skills only. Indeed, task motivation was a salient characteristic of the individual contributions outlined, but I postpone a discussion of this component to Chapter 9. However, it is noteworthy that individual creativity-relevant skills, considered a hallmark of creative people, do not appear as a salient characteristic of individual contributions promoting innovation. Why is it the case that individual creativity-relevant skills were seemingly not important? One reason may be that retrospective case studies are not particularly suited for the investigation of such skills. For instance, when describing the qualities of colleagues, project members may find it more obvious to point out domain-relevant skills and personality characteristics because the identification and articulation of "creativity-relevant skills" may be more difficult. Therefore, I suppose that real-time case studies, providing better opportunities for studying project members in action, would be more appropriate. Thus, individual creativity-relevant skills were not necessarily of little importance in the case projects. Such skills may indeed have been essential. The lack of clear examples may rather be attributed my methodological approach.

project tasks. As such, my study provides further support for the argument that knowledge of a domain is essential for individual creativity (Ref. Amabile, 1983a/b; 1988; 1996; Csikszentmihalyi, 1999; 2001).

At the same time, my study shows that domain-relevant skills are not sufficient to successfully accomplish tasks in a complex problem context defined by an innovation project. To make a creative contribution, individuals must also have *context-relevant skills*, that is, relevant knowledge of the problem context and required technical skills. Aukrust's development of the successful FEM model presupposed substantial knowledge of the extrusion process. Likewise, Breivik and his teammates had to acquire knowledge of the fields of omega-3 fatty acids and pharmaceutical product development. Without the skills required to analyze omega-3 fatty acids and perform relevant procedures in accordance with GMP, the project team would not have been able to obtain the required documentation. Similarly, Breivik's knowledge of the shortcomings regarding methods of analysis and the current market situation was critical because it directed his attention to critical factors of success. Likely, if it were not for Breivik's context-relevant skills in question, it would have been far more difficult for Hydro to succeed with the pharmaceutical and commercial challenges. The Omacor™ project also illustrates the necessity of context-relevant skills through the Vice President's knowledge of the fish oil business and Børretzen's relevant all-round knowledge of pharmacy, production facilities, market trends etc.

Thus, my data shows that professional expertise in the field of study, or discipline, in which one has been trained, is not sufficient for making a creative contribution when operating in a complex problem context defined by an innovation project. To succeed, individuals need context-relevant skills as well. I therefore conclude that *context-relevant skills should be considered as an expertise component of individual creativity*.

Neither Amabile (1983a/b; 1988; 1996) nor Csikszentmihalyi (1999; 2001) discuss this particular type of knowledge. Why not? It may be that these researchers implicitly think of such knowledge as an integral part of an individual's domain-relevant skills. Yet, they do not even mention the possibility that experts sometimes operate within complex problem contexts that represent new domains to them. Accordingly, I believe that Amabile and Csikszentmihalyi simply ignore the importance of context-relevant skills by assuming that creative performance takes place within well-defined domains in which the concern for the problem context is considered the responsibility of others - perhaps those responsible for implementing the creative ideas, i.e. people involved in the "innovation" part (Ref.

Amabile, 1988). As such, the perspectives of Amabile and Csikszentmihalyi are not adequate for understanding individual creativity in complex real-life settings such as innovation projects. This is a major weakness of these systems models of creativity.

I argue that theories of individual creativity must take into account that individuals often operate within complex problem contexts that reach beyond the domain in which they have been trained. Generally, such theories must be consistent with the very conceptualization of innovation as a collective, open-ended activity. In this connection, a broader version of Amabile's componential framework, including context-relevant skills and interpersonal skills on the same level as the existing components, appears to be suitable (See Figure 8.2.2 below).

First, to underscore the importance of context-relevant skills, I suggest that Amabile's expertise-component "domain-relevant skills" should be substituted with the broader term "*task-relevant skills*" including "*domain-relevant skills*" and "*context-relevant skills*" as subcategories.[368]As such, it becomes clear that "domain-relevant skills" is a necessary, but not sufficient, expertise component of individual creativity; it is the *combination* of individual domain-relevant skills and context-relevant knowledge that is necessary (but still not sufficient) for individuals to make a creative contribution in innovation projects. As previously indicated, *context- relevant skills* cover relevant knowledge of the problem context and required technical skills. Such skills depend on experience with the problem context and social interaction (socialization) between "outsiders" ("newcomers") and people operating within the problem context.

Second, I add "*interpersonal skills*" as a fourth component in Amabile's framework. Interpersonal skills cover various skills such as *empathy*, *social skill, know-who, communication skills, political skills*, and *power*. These skills depend on training, experience, formal authority, social capital, and personality characteristics.

Accordingly, I argue that *task-relevant skills* (covering *domain-relevant skills* and *context-relevant* skills) and *interpersonal skills* are essential components of individual creativity along with *creativity-relevant skills* and *task motivation*. None of these components may be absent if some recognizable level of creativity is to be produced.

[368] Indeed, I could have considered the problem context defined by an innovation project as the "domain" in question and pointed up that "domain-relevant skills" thereby cover both the professional expertise in the field in which an individual has been educated as well as knowledge of the domain in question. However, since the very issue of "context-relevant skills" is ignored in existing models of creativity, at least in the models I have outlined in this thesis, I think it is most appropriate to call attention to the overall individual "expertise" required to successfully accomplish an (open-ended) task.

Task-relevant skills	Creativity-relevant skills	Task Motivation	Interpersonal skills
Domain-relevant skills			
<u>Includes:</u> Knowledge about the domain Technical skills required Special domain-relevant talent	<u>Includes:</u> Appropriate cognitive style Implicit or explicit knowledge of heuristics for generating novel ideas Conducive work style	<u>Includes:</u> Attitudes toward the task Perceptions of own task motivation for undertaking the task	<u>Includes:</u> Empathy Social skill Know-who Communication skills Political skills Power
<u>Depends on:</u> Innate cognitive abilities Innate perceptual and motor skills Formal and informal education	<u>Depends on:</u> Training Experience Personality characteristics	<u>Depends on:</u> Initial level of intrinsic motivation toward the task Presence or absence of extrinsic constraints in the social environment Individual ability to cognitively minimize extrinsic constraints	<u>Depends on:</u> Training Experience Formal authority Social capital Personality characteristics
Context-relevant skills			
<u>Includes:</u> Knowledge of the problem context Technical skills required			
<u>Depends on:</u> Experience with the problem context Social interaction (socialization) between "outsiders" and people operating within problem context			

Figure 8.2.2 A Four-Componential Model of Individual Creativity (based on Amabile (1983a/b; 1988)

Still, I do not believe that individual creativity enabled by the confluence of these components is a guarantee of innovation. Innovation is a collective, open-ended activity composed of several, interdependent subtasks, meaning success depends on the outcome of each separate subtask.[369] As such, an individual's accomplishment of his or her specific project task(s) is vital, but not sufficient for innovation success as a whole. Clearly, many

[369] Ref. Chapters 5.7 and 12

conditions for innovation represent circumstances beyond the control of single individuals. It follows that the individuals portrayed in Chapter 8.1 promoted innovation in terms of *increasing the overall probability for success* only. That is, they enabled or facilitated the successful completion of one or more critical project tasks without being in complete control of the outcome of the innovation journey. Accordingly, I believe that the characteristics highlighted in the current chapter do not necessarily represent distinguishing features occurring in successful innovation projects only. Salient characteristics of individual contributions promoting innovation may also be found in innovation projects that do *not* result in a profitable outcome. My point is: *The salient characteristics in question do encourage innovation while at the same time not acting as a guarantee of success.*

To summarize, my study of salient characteristics of individual contributions in the case projects sheds light on individual expertise and skills promoting innovation. In particular, it points up the importance of recognizing context-relevant skills and interpersonal skills on the same level as domain-relevant skills. Such skills are generally ignored in existing perspectives on individual creativity.[370] As such, my study provides new knowledge on organizational conditions for innovation by showing that the likelihood of innovation success increases when the experts involved possess task-relevant and interpersonal skills. Moreover, since my study also exemplifies how interpersonal skills promote creativity at the *collective* level, it highlights conditions for collective learning and powerful collaboration in innovation projects.[371] I therefore conclude that the analysis and discussion of my empirical data in light of the *Person* facet of innovation and creativity offer valuable knowledge on organizational conditions for innovation.

Still, the discussions above indicate that a sole emphasis on single persons fails to take account of the complexity of innovation. In particular, the finding that individual interpersonal skills are important underscores that individuals are part of a large ensemble of specialists whose joint contributions and capacity to play *well together* greatly influence innovation success as a whole. That is, innovation is inherently a *collective activity* depending on individual as well as collective creativity. For this reason, my study of the *Person* facet of innovation and creativity is necessary, but not sufficient to develop proper

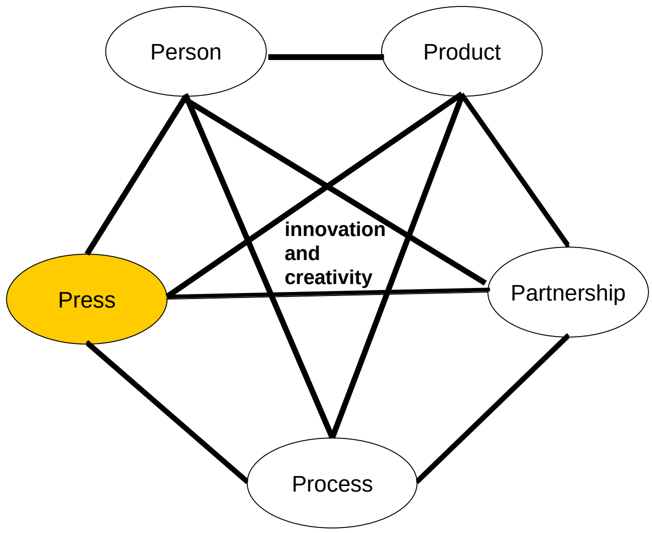
[370] Csikszentmihalyi's (1999; 2001) attention to interpersonal skills in terms of persuasion skills is a noteworthy exception, though, as discussed earlier.
[371] I shed further light on proper work forms and strategies in Chapter 9.

knowledge of organizational conditions for innovation. The other facets must also be taken into account.

Chapter 9 Analysis and Discussion of the Press Facet of Innovation and Creativity

9.1 Introduction

In this chapter I analyze and discuss my empirical data in light of the *Press* facet of innovation and creativity. I highlight factors conducive to creativity in the case projects, structuring the analysis and discussion around the facet-specific questions presented in Chapter 5.4 (see below).



Research Questions in Terms of the Press Facet of Creativity and Innovation:

How do supervisory encouragement and organizational support promote collective creativity in innovation projects?

How does diversity of competence promote collective creativity in innovation projects?

What approaches and work forms increase the likelihood for innovation success?

9.2 How Do Supervisory Encouragement and Organizational Support Promote Collective Creativity in Innovation Projects?

In this chapter I present examples from the Omacor™ project and the PROSMAT "Bearing Channel" project since these projects provide the best illustrations of how supervisory encouragement and organizational support foster collective creativity.

9.2.1 A Presentation of Empirical Examples of Supervisory Encouragement and Organizational Support

The Omacor™ Project

A strong *team spirit* was a hallmark of the Omacor™ project.[372] In April 1988 project manager Breivik reported:

> *…The commitment and enthusiasm among all participants in the projects have been decisive for the fact that we now have a leading international position when it comes to omega-3 concentrates…*[373]

Supervisory encouragement and organizational support contributed to the pronounced team spirit and enthusiasm in the Omacor™ project. In particular, project members call attention to the significance of the active support provided by the Corporate President, the Research Directors at the Hydro Research Center, Porsgrunn, and the principal at the Corporate Center.

The Corporate President, who entered into his position in 1984, had immediately brought innovation into focus. At that time, pharmacy was a "hot" business area subject of great interest in Hydro. The profits in the pharmaceutical industry were twice as large as in other industrial areas. In addition, Norsk Hydro was in a beneficial position, because there were no other large pharmaceutical companies in Norway. Accordingly, when the Corporate President and the other corporate managers in 1984 were introduced to the idea of making an omega-3 "heart medicine", they were really excited. According to one of the seniors in top management, Norsk Hydro had always intended to enter into pharmacy, but the expansions into light metals, PVC, etc. had interrupted these plans. For this reason, the proposal of a project directed at exploring fine-chemicals from fish waste fit well with the

[372] Team spirit is the feeling of pride and loyalty that exists among the members of a team and that makes them want their team to do well or to be the best (Source: COLLINS COBUILD English Language Dictionary). http:///
[373] "Konsentrater av omega3-fettsyrer. Status april 1988." 1988-04-27, p. 20.

visions of top management. The Corporate President is recognized as a driving force creating a positive atmosphere and enabling the initiation of the Omacor™ project. Project members point out that the project would never have become a reality without solid backing from him.

At the Hydro Research Center the (succeeding) Research Directors expressed great enthusiasm and support, providing tangible resources and encouragement. In the words of a project member:

> *…The management staff at the Research Center were willing to arrange things. I remember once, we needed some specific equipment for analysis. At that time, the price was about 23,000 kroner, a sum that exceeded the amount that I could sign for. Then, I made my round to the head of the administration and the research director – and they just signed! That was really an unusual thing to do in light of proper treatment. I was astonished. So,* ***there was a strong belief in the project****!...* (emphasis is mine)

Support from the Research Director heading the center in the period 1987-1989 also enabled the expansion of in-house competence groups such as the establishment of the Department for Pre-Clinical and Clinical Studies. His interest in encouraging the project efforts was genuine, shaped by his professional background (PhD in organic chemistry) and emphasis on research-based innovation. He devoted much attention to the new business area of biotechnology and the Omacor™ project. His "caring" attitude encouraged a stimulating work climate. As one of the project members commented:

> *…Even* [name of the research director] *used to come to our place. He had acquainted himself with our work, and he praised us, telling us that we had done a good job. I find that to be a good way of leading…*

Sigurd Gulbrandsen, characterized as the "oil in the machinery", was the principal responsible for coordinating the research activities and for bringing the project forth within Hydro. Throughout the project period Gulbrandsen showed strong faith in the project. "*Concerning the different steps of this project, we regarded – and still regard – that we were able to document that this was worth pursuing",* he said.

According to project members, Gulbrandsen's unwavering support was a great source of inspiration, promoting the project. In addition, they point out that his style of management contributed strongly to the creation of the team spirit so characteristic of the project. As a project member put it:

…Most managers I have met say one thing and do another. If Sigurd said something, then we knew we could rely on him...

Thus, Gulbrandsen was regarded as a fully dependable principal. In addition, he showed confidence in project members, allowing them a large degree of freedom in how to reach project goals and in opportunities for risk-taking and improvisation, and freedom to make mistakes. The feeling of mutual trust encouraged commitment and created a strong devotion to Gulbrandsen as a superior. One of the project members put it this way:

…Sigurd was very popular(…).But then, he was very well liked, and you could almost paraphrase it and say we could easily do the job and go the extra mile just for him, while there were others we wouldn't' have done that for…

The supervisory encouragement and organizational support illustrated through the examples above made project members feel they were part of a significant, exciting pioneering event. In a way, the Omacor™ project was like Amundsen's quest for the South Pole, racing into Antarctica not knowing whether someone else had already put up a flag. Project members enjoyed working in a company that emphasized the importance of giving priority to new activities. As one of them commented:

…On a business trip abroad I brought with me a brochure about Hydro. The hosts commended the introduction "Hydro -The Everlasting Pioneer!"
This slogan reflected our working climate: We knew we were working in a company that continuously gave priority to innovation…

Moreover, the firm encouragement and support contributed to high levels of task motivation reflected in a strong willingness to do one's best. For instance, project members were willing to lend a hand even when vacationing. As one of them remarked:

…When needed, we worked. There were holidays when I had to send some replies concerning patents, and I used the local bank and fax central. And we made these efforts without really getting any kind of compensation…

Similarly, the following story provides another example of the project members' great commitment. A project member recounted:

> *…We were about to deliver a substance for further processing in Germany. The substance was to be transported by car, and we had ordered tickets for the ferry to Kiel. We had even managed to get hold of a mobile laboratory that we installed in a caravan car. Then, just before the substance was to be handed over, we discovered that it contained too much cholesterol. At this time, we still used fish waste* [as raw material]. *We knew how to deal with it, however… This was in the middle of winter, and we improvised and put up a tent here next to the Research Center. The filtering process had to be performed at low temperatures. We had to work day and night, and there were so many volunteers.* ***So, if you really want to, you find a way to make it happen****…*(emphasis is mine)

Clearly, the project members shared the conviction that hard work would make success. "*We were* **so** *committed to this – this team spirit we had. We would never have succeeded if we felt that we couldn't make it*," one of them, adding:

> *…**Unity brings us forward. If people really agree to solve a problem, they succeed**! The case of the environmental pollution and other by-products in fish oil is a good example. It was a problem we just had to solve – and we succeeded...*(emphasis is mine)

Thus, the examples above suggest that a strong team spirit encouraged by supervisory encouragement and organizational support stimulated collective creativity in the Omacor™ project. I now make a further illustration of how Gulbrandsen's confidence in project members provided them with autonomy boosting their capacity to deal with difficult problems.

Sigurd Gulbrandsen gave project members a large degree of freedom of how to reach project goals. He told project members: "*When needed, you may go wherever you want to, whenever you want to*!" The Hydro researchers never abused this opportunity, but used this trust for the benefit of the project. Among other things, project manager Breivik used it to occasionally leave his office and work elsewhere: "*I find it useful, at times, to get away to work in another place in order to think some different thoughts*", he said. Actually, his visit to a library in Oslo in 1985 turned out to be critical for the further progress of the project. Thanks to this visit he got to learn about an "old" principle for separating fatty acids from cod liver oil.[374] As Breivik recounted:

> *…Regarding the urea precipitation, I remember that the first time I read about it, I was at a library in Oslo. In this case, I read a paper about separation of fatty acids*

[374] Of course, it is possible that the project manager might have got to know about the principle otherwise. Yet, I think the example is interesting, because it suggests that autonomy increases the chance of unexpected opportunities.

> *from cod liver oil using urea precipitation. The researcher reported some problems about the method. The principle was discovered by chance by a man named Bengen in 1940. He was about to separate fat from milk and discovered some interesting things. This was in Germany in 1940, and he was given some months to investigate the issue. A fun thing about this is that when he applied for a world patent in 1940, he was at the wrong place at the wrong time. His invention was taken as a spoil of war by the Americans, and Standard Oil made further research on it. In 1955, a researcher called Marschner published a paper on it in a magazine on industrial chemistry, describing urea precipitation as an interesting principle that future generations of chemists may take into use...*

Breivik and his colleagues found the principle highly interesting and were the first to adopt it, adapting it to fit their case. Their application of the principle formed the basis for their first process patent filed at the end of 1985.

Freedom of process also enabled Breivik's efforts of forming relationships with experts in the field of marine oils, that is, to make use of his *interpersonal skills* and act in the role as a *strategic networker* (Ref. Chapter 8). The contacts and networks were vital for solving critical project tasks.[375] They facilitated Hydro researchers' acquisition of *context-relevant skills*[376], provided important knowledge helping them to reach their goal regarding standardization of methods of analysis, and acted as *social capital* facilitating the approval of Hydro's patent application in the US and the Hydro researchers' official analysis methods.

Moreover, members of the Omacor™ project point out that their freedom encouraged motivation and enjoyment. Comparing this situation with working conditions in recent years, one of them remarked that the freedom and trust so characteristic of the Omacor™ project has been replaced by a greater emphasis on strict administration and control inhibiting creativity. He said:

> *…Nowadays things are quite different (…) There is a heavy administration aimed at keeping track of your activity (…) Of course, we realize that projects are supposed to result in commercial products and that budgeting is important. The problem is that things have become over-administrated, inhibiting the creative potential because of continuous frustration, rather than the adrenalin-fueled feeling of joy you experience when you succeed in creating something new.* ***I think competent researchers would manage to create more value for Hydro if we were allowed more freedom****…*

(emphasis is mine)

[375] For further details, see Chapters 8 and 12.6.
[376] *Context-relevant skills* are relevant knowledge of the problem context and required technical skills, ref. Chapter 8.2.2

So, to summarize, the Omacor™ project shows that supervisory encouragement and organizational support promoted collective creativity by boosting a strong team spirit and by giving project members a large degree of freedom around process. The team spirit made people want the project to succeed, contributing to high levels of task involvement. Freedom of how to reach project goals fostered task motivation and allowed project members to approach problems in ways that made the most of their skills and expertise, thereby increasing their capacity to deal with critical projects tasks.

The “Bearing Channel” Project

In the “Bearing Channel” project, the commitment and support from a top manager at HAEX’s head office facilitated the implementation of recommendations for die maintenance and die design in HAEX plants (*Promotor of power*, ref. Chapter 8). The manager actively supported the emphasis on a close interaction between researchers and industrial people, taking a ”burning interest in this way of working.” In the words of a project member:

> *…To gain access to the Hydro system, the support of the head office in Lausanne acting as a driving force in the project was important. Without their support, things would have been a lot more difficult…I think it all started with* [name of the former HAEX client representative]*, who…after a short time became technical manager in Lausanne. He was the father of it, taking a burning interest in this way of working…I think that if it wasn’t for him, the progress would have been a lot slower, because as a representative of Lausanne he had a decisive power of influence: The word of Lausanne is the law! ...*

Accordingly, the top manager’s support facilitated access to critical resources, thereby facilitating the collective capacity to complete vital project tasks in the “Bearing Channel” project.

9.2.2 Analysis and Discussion

In sum, the examples above suggest that supervisory encouragement and organizational support stimulated collective creativity by providing access to necessary resources, by boosting a collective spirit making people want the project to succeed, and by giving project members a large degree of freedom of how to reach project goals. I now discuss these findings in light of the componential model of individual creativity proposed in

Chapter 8.2.2.[377] This model, adopted at the collective level, appears useful for shedding further light on how encouragement and support influenced collective creativity in the case projects. In particular, this is because it enables a closer study of how supervisory encouragement and organizational support stimulated the individual components of creativity, i.e. *task-relevant skills*, *creativity-relevant skills*, *inter-personal skills*, and *task motivation*.[378] In the following I use the term "skills components" to refer to the non-motivational components of creativity.

Sufficient resources are conducive to creativity (Ref. Amabile, 2001). Provision of critical resources in the case projects enabled project members to involve themselves in tasks and make the most of their overall skills and expertise. For instance, the members of the "Bearing Channel" project would not have managed to develop a proper set of recommendations for the maintenance and design of dies without access to relevant press plants. As such, resources supported collective creativity by allowing project members to use their *task-relevant*, *creativity-relevant*, and *interpersonal skills* for the benefit of the project. Likely, sufficient resources also encouraged intrinsic *task motivation* by acting as a *synergistic extrinsic motivator* in the case projects (Amabile, 1996; Collins and Amabile, 1999).[379] Accordingly, my data suggests that supervisory encouragement and organizational support promoted collective creativity by providing sufficient resources which, in turn, supported all the creativity components directly while at the same time stimulating the "skills components" indirectly through task motivation.

Furthermore, the importance of the team spirit in the Omacor™ project clearly illustrates the significance of *intrinsic task motivation* (ibid). Evidently, the pronounced team spirit expressed high levels of a *collective* motivation to make the project succeed ("*Unity brings us forward. If people really agree to solve a problem, they succeed!*").[380] This motivation

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[377] This model is an extended version of Amabile's componential framework (Ref. Amabile, 1983a/b; 1988; 1996).

[378] *Task-relevant skills* include domain-relevant skills and context-relevant skills. Domain-relevant skills are knowledge of a domain, i.e. knowledge of the field or study, or discipline, in which one has been trained (See Chapter 5.3). *Context-relevant skills* cover relevant knowledge of the problem context and required technical skills (See Chapter 8.2.2.). *Creativity-relevant skills* cover skills stimulating the generation of novel ideas (Ref. Amabile, 1983a/b; 1988).

[379] The finding regarding sufficient resources echoes and complements previous research (Ref. Chapter 5.4). At the same time, the significance of support in terms of sufficient resources appears to be a neglected topic in research highlighting the impact of social-environmental influences on creativity (e.g. Amabile, 1996; Collins and Amabile, 1999; Amabile, 2001). One possible explanation is that the support-resource relationship is self-evident; the allocation of resources naturally reflects managerial support! Accordingly, the very issue of sufficient resources, not conditions *enabling* these resources, is paid attention to. Another explanation is that social-psychologists primarily focus on the importance of individual social-environmental factors as such, not their relationship.

[380] The shared spirit seemed to serve as a *collective resonance* or *synergy effect* (Ref. Senge, 1990) resulting from high levels of individual motivation that, in turn, were reinforced by the team spirit. As such, team spirit appeared to be more than the sum of individual motivation; it had a social quality that made it different from individual motivation.

Moreover, the observed significance of a strong team spirit implicitly points out the importance of *alignment* (Ref. Chapter 5.4).

was essential since intrinsic motivation is conducive to creativity. In fact, no amount of relevant skills can compensate for a lack of appropriate motivation to accomplish a specific task, meaning task motivation is the most important component of creativity (Ref. Amabile, 1983a/b;1988). Clearly, the supervisory encouragement and organizational support contributed to boosting the project members' sense of being part of an important, pioneering event ("*Hydro – The Everlasting Pioneer!*"). As such, the support and encouragement stimulated intrinsic motivation by heightening the sense of *importance/urgency* in the work (Amabile, 1996); project members felt as if their work really mattered to Hydro. In turn, this *intrinsic motivator* made project members want to make the most of their skills and expertise, thereby increasing their capacity to define and solve open-ended tasks in novel, appropriate ways.

The Omacor™ project also shows that supervisory encouragement stimulated intrinsic motivation by heightening the sense of *autonomy/sense of control* (Ref. Amabile,1996; 2001). Clearly, the fact that the principal provided project members with a large degree of autonomy increased their intrinsic motivation.It boosted the "*adrenalin-fueled feeling of joy you experience when you succeed in creating something new*" rather than *"continuous frustration"* resulting from tight managerial control. Acting as an intrinsic motivator, freedom of process thus heightened the project members' intrinsic motivation, inspiring them to stretch their total capabilities (Amabile, 2001). At the same time, the Omacor™ project suggests that autonomy had a *direct* positive influence of the non-motivational components of creativity (Ref. Amabile, 1996; 2001). Freedom regarding how to reach process goals allowed them to approach problems in ways that made the most of their task-relevant, creativity-relevant, and interpersonal skills.

In addition, the autonomy increased the likelihood of *serendipity*[381] (e.g. the library visit) and allowed Hydro people to make connections with relevant external experts. Clearly, without the opportunity to make visits to external laboratories and competence groups, it would have been difficult for Breivik to establish the professional networks so critical for dealing with difficult project tasks. The collaboration and contact with external experts, in turn, provided the Omacor™ project with important expertise promoting *diversity* and *redundancy* (Ref. Chapter 5.4). As such, the Omacor™ also provides an example of how autonomy may encourage other work-environmental factors supporting collective creativity.

[381] Ref. Robinson and Stern (1997)

The most striking finding regarding the relationship between supervisory support and autonomy is the underlying expression of *trust*. Obviously, mutual trust among Gulbrandsen and members of the Omacor™ project enhanced individual motivation and team spirit. Since the issue of trust seems to have received little explicit recognition in literature on creativity and innovation I now make a brief investigation into the role of trust in creativity-encouragement.[382]

In an organizational setting, trust is confidence in someone's competence and in their commitment to the goal (Handy, 2001). Naturally, trust is a prerequisite for granting autonomy that, in turn, stimulates creativity. As such, the significance of trust is reflected in the beneficial effect of autonomy. On the other hand, the Omacor™ project indicates that trust means more than just freedom regarding process. By providing continuous support, and the freedom to make mistakes, Gulbrandsen also expressed an understanding of innovation as a risky venture with no guarantee of where one's explorations would lead (Ref. Barrett, 1998). In this way, he indicated that trust is also about unconditional support and forgiveness for mistakes, provided that the project participants learn from their mistakes (Handy, 2001).

Still, I assume that the most creativity-boosting aspect of trust is *mutuality*: Likely, if members of the Omacor™ project had felt that their large degree of freedom echoed supervisory apathy toward any accomplishments of the project, their motivation would have suffered. Most people need to feel that their work matters to the organization or to superiors. Organizational disinterest thus has a negative impact on intrinsic motivation (Amabile, 1996; 2001). It follows that the beneficial effect of freedom regarding process and freedom to make mistakes is undermined if project members do not have confidence in supervisors' commitment to the project. Similarly, supervisors who do not have faith in their subordinates will probably not allow much freedom regarding process. So, the establishment of mutual trust appears to be a major challenge in attempts to stimulate creativity. In this connection, the Omacor™ project shows that a supervisor who serves as a good role model (Ref. Amabile, 2001) is decisive for the creation of mutual supervisor-subordinate trust. For instance, Gulbrandsen's clear unwavering encouragement and interest in the project made project members confident he was truly committed to the project.

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[382] Apart from Charles Handy (2001) who calls attention to "management by trust" and the seven cardinal principles of trust in relation to his concept of The Citizen Company, I have not found any explicit discussion on trust.

Evidently, his demonstration of trustworthiness in the first place was also important; it boosted project members' urge to prove they were worthy of his trust.[383]

To summarize, my empirical data illustrates that supervisory encouragement and organizational support in innovation projects promote collective creativity in several ways. First, *support and encouragement in the sense of access to critical resources stimulate all components of creativity*, enabling people to make the most of their expertise and acting as an extrinsic synergistic motivator increasing task involvement. Second, *support and encouragement stimulate intrinsic motivation and team spirit by heightening project members' sense of importance/urgency in the work*. Third, *supervisory encouragement in terms of provision of autonomy boosts intrinsic motivation by increasing project members' sense of self-determination*. In addition, it has a direct positive influence on the non-motivational components of creativity by allowing people to approach problems in ways that make the most of their overall skills and expertise. As such, autonomy may also promote serendipity and other antecedent factors such as diversity and redundancy. The beneficial impact of autonomy on collective creativity presupposes a mutual supervisor-subordinate trust.

9.3 How Does Diversity of Competence Promote Collective Creativity in Innovation Projects?

> *…Creativity means the ability to rethink - to think in other directions than you usually do. In order to make it, interaction with other professional areas is needed. It's difficult to be creative within your own restricted field of work. Consequently, creativity is encouraged when you mix with people representing other backgrounds. The New Die, brought to light in a mixed workshop, is really a good example of that, you know…*

This statement, made by a member of the "Die Life" project, summarizes what appears to be the most salient creativity-booster throughout the case projects: *Collaboration between people with diverse competence.* In the following I present examples of how diversity of competence stimulated collective creativity in the case projects.

[383] Likely, the managers' dependability and confidence in project members also created a positive spiral effect in which his trust made project members willing to stretch their capacities. In turn, the project members' proof of creativity enhanced the manager's trust and so on.

9.3.1 A Presentation of Empirical Examples of Diversity of Competence

The “Die Life” Project

The “Die Life” project, aimed at increasing die life of thin-walled hollow AA7000 dies, provides a solid illustration of the positive influence of diversity of competence on collective creativity. Participants argue that the interdisciplinary researcher collaboration and the close interaction between research and operational work were vital for solving the die life problems. Among other things, HAST employees claim that the business unit would hardly have managed to solve the problems without the involvement of external competence. One of them said:

> *…We would not have succeeded if it wasn’t for the involvement of SINTEF – the theorists, the numerical capacity, and “material people. Of course, we might have managed to do it, but that would have implied a lot of trial and error, and in 2000 you definitely do not take that approach!...*

Similarly, another HAST employee commented:

> *…The involvement of these people was highly valuable. They have so many ideas. Especially, when you’re grouping your way in the dark, it’s important to get other impulses…*

Actually, the very idea of involving “outside” competence is recognized as a creative approach. As a project member expressed himself:

> *…Personally, I think we were highly creative when we, in contrast to what is often the case, realized that we couldn’t solve this problem alone; we had to look outwards and involve people from a variety of disciplines… because an internal approach usually results in bad solutions…*

The external academic head competence included competence on measurement technology, FEM modeling, and materials technology. For instance, material technologists at SINTEF studied ”damaged” dies in order to find out *where* – and in some cases also *why* - cracks appeared. At the same time, they provided relevant material data for use in the FEM computations, thus increasing the reliability of the numerical simulations. Similarly, the modelers performed computations assisting the material technologists in their work. The FEM stress analysis, resulting from a joint collaboration between modelers and material technologists, offered vital information about optimal die design (e.g. the limitations of the existing design principle, leading to the "dramatic conclusion" and the birth of the New Die). Accordingly, "*numerical computations were really alpha and omega for making progress*," as a HAST employee put it. Likewise, project members emphasize the importance of diverse practical expertise. One of them commented:

> *…The general knowledge of extrusion dies was very important. The die experts knew about critical factors and had great competence on die design as well as experience with hollow profiles and dies…*

In this connection, HAST employees also highlight the value of being allowed to discuss the die life problem with experts in Hydro Extrusion, the very "enemy" before Hydro's acquisition of Raufoss Automotive Structures.[384] As one of them said:

> *…The fact that we got this opportunity to discuss the matter on a broader basis, get impulses from Extrusion, raising some critical questions, was important…*

In the words of another project member:

> *…Even though we've been working with profiles since 1963, Hydro has had activities everywhere too, and regularly engages new people who may have a different view on things…*

Project members also point out the mutual benefits derived from thorough practical competence and academic expertise. One of them put it this way:

> *…During several years we've systematically built up competence on extrusion, meaning that we have sufficient competence to realize when we were heading in the wrong direction and make the necessary corrections. This is an industrial competence, matching the competence found within the SINTEF or NTNU system…*

More specifically, broad hands-on experience contributed to competent interpretation of test results, forming a sound basis for new investigations. For instance, when participants with practical die experience were presented results from numerical simulations through visual displays of hot spot areas, they provided feedback and "smart solutions" regarding proper changes. The researchers, on the other hand, collectively provided necessary

[384] Until the Hydro acquisition, Raufoss Automotive and Hydro Aluminium Extrusion (HAEX) had lived a "cat-and-dog-life", being physically separated by a three meter thick tall wall, "the Berlin wall".

competence on the materials technology and FEM modeling enabling the numerical simulations in the first place. At the same time, their competence included a systematic scientific approach to the die life problem, forming a powerful contrast to the traditional industrial practice of “trial and error.” Accordingly, the integration of thorough die-technical competence and interdisciplinary academic expertise was necessary to deal with the die life problem. As a project member explained:

> *…First, it was important to involve people with years of experience from the field. Such people usually have some ideas about the origin of the problems. Next, it was important to involve people representing a more cross-disciplinary expertise …people who are capable of pinpointing the problem, of showing it, of demonstrating it. Accordingly, it’s the combination of the long hands-on experience and cross-disciplinary head competence in alternative areas* [that is decisive]…

Furthermore, the “Die Life” project shows that beneficial diversity was also about thinking beyond the specific context of extrusion. In particular, project members emphasize the importance of “outsiders” being invited to “brainstorming” workshops throughout the project period. One of them recounted:

> *…I think that…in the project period one made something really important: Breaking oneself off from the traditional thinking, including people from other areas to a couple of open brainstorming meetings to release thinking a little. This was because the efforts had reached a deadlock. I think the idea of opening up, involving other people, thereby leaving the traditional footsteps, was the main key for making progress in the direction we gradually chose…*

Similarly, subproject manager Rystad argued:

> *… New ideas may come from anyone. They do not necessarily come from people with a particular technical competence! I have often experienced that people with a practical, rather than a technical background, have proposed thought-provoking questions providing new approaches. Often one single question is enough. That’s a fundamental part of brainstorming sessions…*

The workshop arranged in October 1996 sheds further light on the above statements. Taking into account that the existing die design had reached its limits with respect to die life, the challenge of doubling die life was brought into focus. Subproject manager Rystad invited a great number of persons with diverse competence, including project members at SINTEF and Raufoss, representatives from the steel producer and the tool manufacturer, people from Hydro Extrusion and the R&D center, Karmøy, and Automotive staff members working on other forming processes. The brainstorming workshop resulted in numerous, different ideas and recommendations for further progress. Evidently, several ideas challenged existing ways of thinking. As a project member enthusiastically claimed:

> *…Lots of suggestions were made: Why do we not do it like this? The material technologists and mathematicians proposed their ideas, while the practitioners in the press plant had other ideas…*

Among other things, the workshop resulted in a number of principally different die designs. The ideas were evaluated through numerical simulations and further testing revealed that the New Die was the most promising concept regarding reduction of hot spot stress. From my point of view, the most striking feature of this concept is the fact that is was derived from another aluminum forming process within Hydro Automotive. Similar to aluminum extrusion, the other process involved the use of dies, putting strong demands on die design. One of the die design principles is similar to the New Die concept. As such, Rystad's emphasis on inviting staff members "outside" the field of extrusion brought this particular principle into focus.

So, to summarize, the "Die Life" project shows that diversity of competence boosted collective creativity in two ways. Diversity provided *requisite variety* (Ref. Nonaka and Takeuchi, 1995; Morgan, 1997) of expertise needed to match the complexity surrounding the die life problems. In addition, variety of expertise, thinking styles, and perspectives contributed to new ideas challenging traditional, limited ways of thinking and doing.

The "Bearing Channel" Project

The aim of the "Bearing Channel" project was to develop proper FEM models[385] that could provide a deeper understanding of flow in the bearing channel, i.e. the complex mechanisms taking place inside a die during extrusion.[386] This was a prerequisite for obtaining better insight into the causes of surface defects.

The "Bearing Channel" project was carried out in close collaboration with two in-house Hydro projects. Project members regard the close interplay between researchers and industrial people as decisive for the positive outcome of the project. First, the involvement of SINTEF researchers with material technological competence, competence on FEM

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[385] FEM models are mathematical models based on the Finite Element Method (FEM), ref. Chapter 6.1.4.

[386] The *bearing channel* is the surface along which the aluminum flows and is shaped (Ref. Chapter 6.3).

modeling, and a scientific approach, was necessary for developing new knowledge about flow in the bearing channel. Their systematic die studies enabled the proposal of hypotheses for the formation of visible surface defects. In turn, the hypotheses provided a basis for the development of numerical models that could predict surface defects and matching descriptions on how to avoid them. The resulting 2D FEM model is regarded as a breakthrough in communicating and explaining the complex mechanisms taking place inside a die during extrusion. As Trond Aukrust, the subproject manager, commented:

> *…The 2D model was important, because I know people with many years of experience from extrusion, for instance the manager of the Dies Fit For Use project. He had worked with dies for many years. According to him, the 2D model made him understand 50 or 80 percent of what he previously did not understand about die design…*

Accordingly, expertise on numerical simulation was vital. In the words of a project member:

> *…the mathematical modeling contributed to a good understanding of what happens inside an extrusion die during the process. We would hardly have obtained this without the fundamental modeling part...*

At the same time, relevant academic expertise was not sufficient for success with the project efforts; practical competence was also needed, not least in connection with the verification/validation work. People with hands-on expertise enabled validation of the modeling efforts. For instance, local plant operators frequently studied profiles and dies, measuring geometric parameters of the bearing channel. In this way, they provided the researchers with critical information about when things started to work poorly and why. Yet, rather than pointing to *either* the academic competence *or* practical expertise, members of the "Bearing Channel" project emphasize the importance of the *joint* academic-practical efforts and the mutual benefits of the academic and practical activities. A Hydro researcher claimed:

> *…I think the involvement of different working groups and people ranging from those who face problems in daily work operations to the researchers with a PhD in theoretical physics, working in their offices, promotes creativity. Succeeding in making all these things work together fostered an inspiration and creativity that otherwise would not have been obtained that easily – at least not with the same results…*

In particular, the joint documentation efforts are recognized as a sound working method combining the "*best of the academic world with practical industrial projects*," as one of the project members put it.[387] The mathematical modeling work provided a clear physical description of what happens inside a die during extrusion, thereby documenting the practical matters. At the same time, practical testing facilitated validation of the modeling results. A Hydro researcher summarized the collaboration in the following way:

> …*We managed to document the relationship between the worn bearing surface, combining this with 2D and 3D modeling of flow in the bearing channel, providing a theoretical description of it (…) We managed to validate that different flow paths influence surface quality. Besides, we succeeded in our documentation in practice. We ran experiments at the SINTEF lab press as well as practical industrial tests, finding the parallels.* ***That's a good way of combining practical experience and theoretical competence****…*
> (emphasis is mine)

Thus, similar to the "Die Life" project, the "Bearing Channel" project calls attention to the beneficial influence of diverse academic head competence combined with diverse practical competence. The diversity facilitated the joint accomplishment of complex tasks that neither external academic researchers nor people with hands-on competence would have managed to complete alone.

The "Empirical Modeling" project

The *Empirical Modeling* project aimed at utilizing process data logged at extrusion presses to predict and optimize process parameters and thereby obtain better process control and productivity.[388] During the project Tom Kavli, the subproject manager, and SINTEF colleagues managed to develop software tools based on empirical models that could predict press speed for new sections. These software tools, the so-called *Speed Predictor*[389] and *Shape Finder*[390], are regarded as significant innovations in the industrial and academic context.

To illustrate the significance of diversity in the "Empirical Modeling" project I first present an example showing how the SINTEF-researchers approached a specific challenge.

[387] I elaborate on this in Chapter 9.4
[388] Empirical modeling is about modeling the relationship between parameters grounded in analysis and interpretation of empirical data.
[389] Speed Predictor is a software tool that uses empirical models to predict the press speed, productivity, and production costs for new sections based on their shape.
[390] Shape Finder is a software system searching a database of section shapes for any shapes that are similar to a specific (new) section, displaying key data for these.

During the first year and a half, Kavli and co-workers collected process data from three extrusion plants. In parallel, they started developing software for efficient analysis of these data. In the early phase Kavli and his teammates also noticed that the geometry of sections and dies was an important input to empirical models. In order to do statistical analysis and modeling of process data, the SINTEF researchers thus needed to be able to relate the process data to section shapes.[391]

When Kavli and co-workers carried out analyses based on the early versions of the software for process and shape analysis, the results revealed large speed variations in the same die at all extrusion plants. These variations made the data less suitable for developing empirical models able to estimate process parameters and productivity for new sections. To identify the reasons for the variations, the SINTEF researchers arranged a large meeting at the press plant at Karmøy. They presented and discussed their findings with, among others, all the press operators responsible for setting the process control parameters. The press operators recognized the variations, providing several explanations for the situations without being able to give a sound answer to the problem. Based on this response, Kavli recommended the initiation of an in-house HAEX project to work on the problem. At the same time, he and his colleagues concluded that the available process data and CAD drawings were not sufficient for building empirical models. They realized that they also had to make use of the operators' practical knowledge and experience. Thus, both academic head competence and industrial expertise were necessary to develop proper empirical models.

Likewise, the accomplishment of evaluation and implementation projects required both academic and practical expertise. The evaluation/implementation efforts, encouraging a close communication between industrial people and the SINTEF researchers, provided important knowledge necessary to improve the empirical models and develop the evaluation prototypes in "the right direction", as Kavli expressed himself.

The "Empirical modeling" also sheds light on the favorable influence of diversity in the sense of the interdisciplinary composition in the relevant SINTEF department. As Kavli said:

> *… The department I worked in was interdisciplinary. They had competence on computational geometry, data analysis, empirical modeling and optical processing. All these competence areas were represented within one, relatively limited group…*

[391] SINTEF report no STF72 F00624 2000-12-18 (restricted) New Modelling Techniques for the Future Extrusion Technology. Subproject: Empirical Modelling. Final Summary Report.

Among other things, the diversity of competence was a prerequisite for the development of Shape Finder. Kavli said:

> *…Seeing the idea of Shape Finder required creativity. It might be that many people may get this idea. However, **actually believing that the idea may be realized presupposes a larger degree of freedom and a little knowledge across the field…** Because if this were a department specialized in optical processing, we would not have had the necessary competence on computational geometry…*
> (emphasis is mine)

In addition, the interdisciplinary collaboration stimulated the creation of new ideas, challenging traditional discipline-based assumptions. As Kavli explained:

> *…There is a lot of internal communication in that group. In fact, it is like a team constantly exchanging large amounts of information. You have the professionals that keep asking: Why don't you do that? Why can't you do that? There are a lot of ideas whirling in the air…*

Thus, to summarize, the "Empirical Modeling" project shows that diversity of competence boosted collective creativity in two ways. Diversity provided *requisite variety* of expertise needed to match the complexity posed by the idea of utilizing process data to optimize and predict press parameters. In addition, variety of disciplinary expertise, thinking styles, and perspectives contributed to new ideas challenging traditional, limited ways of thinking and doing.

The Omacor™ Project

The aim of the Omacor™ project was to develop a therapeutic pharmaceutical based on omega-3 fatty acids from fish oil. The project implied for Norsk Hydro to enter into the complex world of pharmaceutical product development in which the company had no previous practical experience. This world represents the open-ended task of dealing with two interacting challenges, the "pharmaceutical" and "commercial" challenges, respectively.[392] Because Hydro was not a pharmaceutical company, the challenges were even greater. First, pharmaceutical development was a new business area in the company,

[392] The "pharmaceutical" challenge includes the work needed to obtain marketing authorization for a therapeutic pharmaceutical. The "commercial challenge" concerns the efforts required to transform an approved product into a *commercially* successful product. See Chapters 6.5.2 and 12 for a further elaboration of the dynamics of pharmaceutical product development.

and no other Norwegian companies had competence on original pharmaceutical development. Second, omega-3 fatty acids had been the focus of extensive research for more than fifty years, meaning the prospects for new "omega-3 patents" were limited. Third, the very fish oil itself was a more unpredictable and expensive raw material than were pure chemical compounds. Yet, Hydro managed to become the first company worldwide to develop fish oil into a patented therapeutic pharmaceutical in large-scale production. Several project members link the success to diversity, pointing out the importance of interdisciplinary, cross-departmental, and inter-organizational collaboration. In particular, people mention the fruitful interdisciplinary, cross-departmental cooperation at the Norsk Hydro Research Center, Porsgrunn. "*I think we would not have succeeded if it was not for that,"* one of them said, explaining:

> *…We managed to compose a project team consisting of people with different skills and were able to benefit from it…We could benefit from the entire range of diversity in the research center. There were people with process knowledge, some with laboratory experience, biochemists, highly competent researchers with analysis expertise, people who, as time went by, specialized in the field of pharmaceutical product development and corresponding laboratory practices, etc. We managed to get this interaction going across professional fields and limits…*

Moreover, people emphasize the importance of collaborating with other Hydro units and external competence groups.[393] For instance, patent experts at Hydro's patent office played a decisive role for patent issues. "*Hydro is really good at writing patents. That's why they have succeeded so well in the area*," a researcher commented. Likewise, the Vice President of the Hydro Agriculture Business Unit, heading the areas of fish farming and fish feed in the period 1986 through 1990, had trade competence on fish oil and fish feed.[394] Thanks to his competence, Hydro gained access to high-quality fish oil, production technology, and relevant competence through the acquisitions of two Norwegian fish oil companies. Similarly, collaboration with internationally recognized experts on omega-3 fatty acids and pharmaceutical product development assisted Hydro researchers in dealing with the strict, comprehensive documentation requirements for therapeutic pharmaceuticals. In particular, this is because the close contact with these experts facilitated the acquisition of necessary

[393] I elaborate on the issue of networks in Chapter 12.
[394] Chapters 8 and 12 provide further details on the Vice President's role in the Omacor™ project.

context-relevant skills[395] in the sense of competence needed to meet the requirements of Good Manufacturing Practice (GMP).

Still, project members point out that insufficient competence retarded the progress of the project, in particular the work required to solve the "commercial" challenge. Among other things, they claim that the project suffered from a lack of expertise concerning strategic planning of clinical paths, insufficient marketing expertise, and scant market competence. One of them argued:

> *…Omacor™ would have seen a more rapid development if one had engaged people who were really experts in this. If we had had a professional organization that really mastered this business, we would have reached our goals a long time ago...*

Adding strength to this argument, another project member stated:

> *…Competence has constantly been insufficient. And that has probably influenced the actual progress of the project. It has taken too long… Here you needed special competence in so many areas…You should not think that you are competent to do everything just because you are the largest Norwegian business group…You have to put your finger in the ground and ask: What kind of competence do we need? That's what they did in the area of oil & gas. Here you employed people with a specialist competence and offered them sky-high salaries in order to develop the adventure of the oil business. You should have done the same thing within pharmacy, too…*

Thus, the Omacor™ project indicates that Norsk Hydro underestimated the need for relevant competence when entering into the field of pharmacy.

In sum, the examples from the Omacor™ project illustrate that diversity of expertise stimulated collective creativity by contributing to the variety needed to match the complexity embodied in the "pharmaceutical" and "commercial" challenges. At the same time, it shows that insufficient variety of expertise retarded the progress of the project. As such, the project suggests that sufficiently diverse expertise promotes collective creativity, whereas the opposite is true for insufficient diversity.

9.3.2 Analysis and Discussion

In sum, the four case projects shed light on how diversity of competence influences collective creativity, thereby increasing the likelihood of innovation success.

[395] Context-relevant skills are relevant knowledge of the problem context and required technical skills (Ref. Chapter 8).

First, the projects exemplify the importance of *requisite variety* (Nonaka and Takeuchi, 1995; Morgan, 1997): When a project team/network possesses requisite variety of expertise, the team members collectively have the capacity to deal with the challenges posed by the project objective. Similarly, insufficient variety negatively influences collective creativity. For instance, the PROSMAT Extrusion projects show that diverse academic competence *in combination with* diverse practical competence stimulated creativity; neither diverse academic competence nor practical competence alone was sufficient to meet the variety and complexity set by the project context. As such, the results of the joint efforts were beyond that of any single contributing field of expertise. Likewise, the Omacor™ project demonstrates that requisite variety enabled project members to successfully deal with specific project tasks. Still, lack of critical specialist knowledge implied insufficient variety with respect to the *overall* requirements set by the project goal; this shortage resulted in "unnecessary" mistakes and retardation of progress. Accordingly, my empirical data shows that diversity of competence stimulated collective creativity by facilitating requisite variety of expertise needed to match the complexity posed by the purpose of innovation projects.

My componential model of individual creativity, adopted at the collective level, provides a similar, yet complementary, explanation for the importance of diversity.[396] As discussed in Chapter 8.2.2, this framework conceptualizes creativity as a composite phenomenon including *task-relevant skills* (domain-relevant and context-relevant skills), *creativity-relevant skills*, *interpersonal skills*, and *task motivation*.[397]

When viewing my data on diversity in light of the model, it becomes evident that individual task-relevant skills were a necessary, but not sufficient, condition for collective creativity. No amounts of individual task-relevant skills could compensate for a lack of critical domain-relevant and context-relevant skills in the project team/network as a whole. As such, my model demonstrates the limitations of a sole emphasis on individual creativity (the *Person* facet). Simultaneously, the framework suggests that requisite variety implies that the team members *collectively* possess the necessary task-relevant skills, i.e. domain- and context-relevant skills. Such competence is the basis for performance in a given problem context. Accordingly, when a project team lacks relevant competence (e.g. the

[396] As discussed in Chapter 8.2.2, this model represents an extension of Amabile's componential framework (Ref. Amabile, 1983a/b; 1988; 1996).

[397] *Task-relevant skills* include domain-relevant skills and context-relevant skills. Domain-relevant skills are knowledge of a domain, i.e. knowledge of the field of study, or discipline, in which one has been trained (See Chapter 5.3). *Context-relevant skills* cover relevant knowledge of the problem context and required technical skills (See Chapter 8.2.2.). *Creativity-relevant skills* cover skills stimulating the generation of novel ideas (Ref. Amabile, 1983a/b; 1988).

Omacor™ project), collective creativity is undermined. Thus, *diversity of competence promotes collective creativity by contributing to requisite variety of individual task-relevant skills, which is a necessary component of collective creativity.*[398] It is also evident that requisite variety has a *direct* impact on collective task-relevant skills. This finding supports Amabile's (1996) suggestion that diversity may influence the non-motivational components of creativity directly– at least when it comes to the collective level.

Furthermore, when viewing my data in light of *creativity-relevant skills*, the second component of my componential model, it becomes evident that diversity of expertise also stimulated the collective capacity to create novel ideas. The "Die Life" project shows how brainstorming among people with diverse competence resulted in many different ideas for doubling die life. It also demonstrates how a design principle familiar to workers in one context challenged others' assumptions of what a die may look like. The "Empirical Modeling" project illustrates that interdisciplinary teamwork helped people think outside their disciplinary "boxes". Experts on optimal processing would hardly have imagined a real Speed Predictor if it were not for the introduction of the "alien" perspectives of people working in the field of computational geometry. Similarly, the close contact between people with various domain-relevant skills fostered regular questioning and surfacing of tacit cognitive models: "*Why don't you do that? Why can't you do that?*"

Thus, my empirical data points out that teams composed of people with various intellectual foundations and approaches to work, combine and combust ideas in novel and useful ways (Amabile, 2001). At the same time, the data show *why* it is so: In cognitive heterogeneous teams each person contributes with his or her idiosyncratic frame of experience and knowledge, seeing problems and opportunities through a particular lens (Leonard and Swap, 1999). Because different individual lenses are put together, the result is a kaleidoscope of ideas - a "*creative abrasion*" developed from the multiple points of view (ibid.). This synthesis implies numerous ways of *framing* a task. Simultaneously, a collection of diverse individual frames stimulates *reframing* through the questioning and surfacing of different tacit assumptions (Bolman and Deal, 1987). As such, diversity in the form of diverse competence fosters double-loop learning (Argyris and Schön, 1996).

Moreover, my empirical data indicates that *collective creativity-relevant skills enabled by diverse competence (task-relevant skills) represent a distinct collective quality*. Such

[398] When speaking of collective creativity, I hereafter simply use the terms "collective task-relevant skills" and "collective creativity-relevant skills" to point out that team members *collectively* possess the necessary task- and creativity-relevant skills.

skills embody a group phenomenon that is qualitatively different from the sum of individual creativity-relevant skills. Actually, my empirical data suggests that *a high level of collective creativity-relevant skills does not necessarily require high levels of individual creativity-relevant skills*. Likely, the idea of the New Die design was not a product of the HAST employee's creativity-relevant skills, but of his context-relevant skills. It was the very "mixing" of people representing different backgrounds that provided the participants with the collective creativity-relevant skills. As such, the great advantage of the heterogeneous teams/networks over individuals is that even if individual members think within the boundaries of their own thinking, the very presence of diverse perspectives implies that team members collectively hold the necessary creativity-relevant skills (Leonard and Swap, 1999).

Hence, my study shows that *diversity of competence promotes collective creativity by supporting collective task-relevant and creativity-relevant skills, two necessary components of collective creativity*.[399] It also indicates that collective creativity-relevant skills enabled by such diversity represent a distinct collective quality; they embody a group phenomenon that is qualitatively different from the sum of individual creativity-relevant skills. Moreover, I find that diversity has a direct impact on task-relevant and creativity-relevant skills. In this way, my study supplements previous research by showing that diversity, at least at the collective level, has a direct impact on the non-motivational components of creativity.[400]

[399] When viewing these findings in light of *interpersonal skills*, the fourth component of my componential model, it is natural to assume that diversity of competence also contributes to increased variety of individual interpersonal skills. In turn, high levels of various interpersonal skills increase the project members' capacity to benefit from diversity of competence. Clearly, without great empathic skills, listening skills, mutual acceptance, mutual trust, and mutual capacity to support and "comp", fruitful collaboration between people with different expertise is difficult. However, since my empirical data on the relationship between diversity of competence and interpersonal skills is weak, I have not shed light on this issue in the current discussion.

[400] When it comes to *task motivation*, the third component in my extended version of Amabile's framework, my empirical data does not shed further light on the motivational impact of diversity.

9.4 What Approaches and Work Forms Increase the Likelihood for Innovation Success?

9.4.1 A Presentation of Approaches and Work Forms in the Case Projects

The "Die Life" Project

As previously discussed, Sigurd Rystad, the subproject manager of the "Die Life" project, emphasized the importance of involving people with diverse practical and academic competence to deal with the die life problem. At the same time, he acted as a *strategic networker* and *co-generative learning booster* (Ref. Chapter 8), orchestrating frequent and intensive interaction between relevant people through regular *meetings*, *workshops* and a *parallel processing* strategy.

During the pre-project period Rystad arranged several meetings to facilitate the exchange of experiences and come to decisions about working methods and approaches.[401] The pre-project meetings, involving local project members and people from SINTEF, NTNU, the HA Extrusion group, the steel manufacturer, the Hydro R&D Center at Karmøy, and the Automotive Research Center at Raufoss, enabled a thorough evaluation of previous research results and working methods. People shared information revealed from literature reviews to learn about experiences and results obtained by others. In addition, they examined methods and results achieved in the EXPOMAT period. All together, the pre-project meetings resulted in several recommendations and suggestions for the main project.

Furthermore, the arrangement of brainstorming workshops was a hallmark of the main project period. The workshops fostered information sharing and the creation of new ideas guiding further process steps. I here illustrate how they facilitated HAST's capacity to deal with two specific challenges in the project.

Shortly after the "Die Life" project started, stress analysis and practical tests revealed that that the die design at that time had reached its limits with respect to die life; further optimization was not possible. Rystad and his colleagues realized that a new die design was needed. This conclusion was a milestone in the project, forcing rethinking. "*We simply hit*

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[401] I shed light on the significance of pre-projects later in this chapter.

the wall. We could not make any further progress!" a HAST employee stated.[402] Facing this challenge, Rystad decided to arrange a large brainstorming meeting to generate ideas for a new die concept. Along with the project members, he invited several external experts. The participants worked in small groups, discussing questions such as: How may the next generation extrusion die for AA7000 look like? How may a quantum leap be reached? Which R&D areas are essential for attaining a considerable increase in die life?[403] The discussions revealed the need for a better understanding of crack mechanisms, i.e. knowledge about how and why cracks appear and destroy dies, and they called attention to appropriate extrusion process management. In addition, the workshop resulted in the proposal of different die designs. This information guided subsequent project efforts. For instance, die design ideas were organized into five or six main groups and were evaluated through numerical simulations to provide suggestions for further work. In turn, promising concepts were further tested. Eventually the New Die appeared to be the most favorable regarding reduction of hot spot stress. Actually, in 1999 the project team managed to reach a die lifetime that far exceeded the original target.

The development of test methods for accurate measurement of stress in dies during press runs was another challenge in the "Die Life" project. Appropriate test methods were seen as necessary for verification of numerical simulations. The work aimed at developing such procedures was retarded because of severe problems of finding suitable measuring equipment. In addition, searches for people with relevant competence on high temperature stress testing were negative. Accordingly, Rystad and project colleagues concluded that no one else seemed to be capable of doing relevant measurements at operating conditions, i.e. extreme temperatures and pressure. These problems reflected the great challenges involved in the actual measurement efforts. As one of the researchers explained:

> *…Doing measurement in cases of stable temperature is very easy. However, once you start having temperature gradients and temperature shifts of 50 to 100 degrees Celsius over a few minutes,* ***you're facing the great challenge of being able to do any measurements at all****...*(Emphasis is mine)

[402] Clearly, the acute crisis characterized by "catastrophically short" die life, and "astronomically high" die costs also exemplifies *creative chaos* (Nonaka and Takeuchi, 1995). Project members point out that the urgent need to deal with the situation stimulated creativity. "*It was an emergency situation. On the other hand, without this pressure, things take twice as long*!" one of them said, adding: *Unfortunately, we see that large inventions emerge in war- time situations – without comparisons*." Thus, the brainstorming workshops illustrate the importance of collective reflection as a means for coping with the "breakdown" of routines, habits, or cognitive frameworks (ibid).
[403] PROSMAT New Modelling Techniques for the Future Extrusion Technology. Subproject 1: Strength Analysis and fracture mechanics. Minutes of Meeting (Meeting held 1996-10-21) 1996-12-03.

Still, the project members continued their efforts. In March 1998 Rystad arranged a large workshop on measurement techniques, inviting among others, SINTEF researchers and professors at the University of Oslo.[404] During the workshop the participants discussed a number of relevant measurement techniques. One of the professors proposed the use of a specific press sensor. Along with his colleague, who was a member of the PROSMAT Extrusion steering committee, this professor had previously worked on test methods involving the sensor in question. The "Die Life" researchers agreed to use this technology as the basis for their development of appropriate test methods. The development of a "pressure sensor" became the main objective of a PhD study initiated in January 1999. According to project members, the work on measurement technology provided important, new knowledge about the extrusion process. The "pressure sensor" is regarded as a main outcome of the project, "providing unique possibilities for looking into the process during aluminum extrusion."[405]

The *parallel processing* strategy implied that the researchers and industrial workers approached the die life problem in parallel, each group contributing with unique, complementary skills. SINTEF researchers carried out fracture mechanism studies and FEM stress computations, while an internal HAST team, collaborating closely with the steel manufacturer, focused on maintenance procedures for dies and issues concerning steel quality and extrusion process management. Tight coordination of the parallel activities through meetings fostered redundant information. FEM stress computations provided suggestions for proper die design, while practical testing of the results contributed with relevant information for further theoretical work. Project members argue that the parallel strategy facilitated faster progress than the traditional approach in which ideas are sequentially investigated. Subproject manager Rystad said:

> *…There was no time to lose…Unfortunately, in this business, if you're about to develop and test an idea, you first have to make drawings. Next, you have to produce it, run it, test it, and finally verify the results. Using this approach, you inevitable reach the conclusion that you're able to test only three to four ideas every year. This was a very critical phase. As a consequence, we aimed at working more in parallel directions and push the matter…*

Similarly, pointing up that the parallel strategy enabled rapid feedback and progress, one of his project colleagues commented:

[404] Minutes of Meeting. Workshop 1998-03-18
[405] 2001 Report NFR HA R&D Materials Technology.

> …***Running industrial activity in parallel with a research project was a criterion of success****. This is because a sequential approach in which you work systematically, produce reports, read reports, and finally aim at industrializing results, takes too long. Besides, the people working on the task are not given feedback as soon as required. Consequently,* ***a parallel industrial-research approach is also a prerequisite for rapid changes****…*(Emphasis is mine)

Thus, the “Die Life” project illustrates that meetings, workshops, and an overall parallel processing strategy were beneficial approaches. The work forms facilitated a close interaction between research and operational work, promoting the collective capacity to define and solve critical open-ended problems.

The “Bearing Channel” Project

The “Bearing Channel” project sheds further light on approaches and work forms enabling a close dynamic interaction between researchers and industrial people. In particular, it exemplifies the importance of staging for communication and interaction in the problem owner’s local settings.

Visits to extrusion plants and dialogues with local experts helped SINTEF researchers grasp essential industrial problems. As subproject manager Trond Aukrust recounted:

> *…Getting first-hand experience with the process and observing what works and what does not work, is really useful. Pure thinking in your office is simply not enough! The contact with the industrial projects was decisive for the outcome of PROSMAT, because of the knowledge or competence you acquire by being out in the plants, observing what’s going on. For instance, you get a thorough understanding of the process and the die technology, and you learn about bottle necks and things at the heart of the process that are decisive for achieving the desired quality…*

Accordingly, close, direct interaction between external researchers and local workers made the former acquire important context-relevant skills fostering sound problem definition (Ref. Chapter 8).

In this connection, members of the “Bearing Channel” project call attention to the importance of external researchers interacting with local workers *directly*. The “Bearing Channel” project implied a break with HAEX’s traditional way of involving external researchers in R&D projects. Usually, only in-house researchers such as Technical Service staff members had direct contact with the business units, assisting local workers and learning about the particular needs of and problems in daily production. As a consequence, whenever external research competence was needed, “outsiders” were handed ready-made problems defined by Hydro researchers. This “relay race” approach often meant that external researchers were not given the opportunity to develop a thorough “feeling” for the practical implications of their work. As one of the project members explained:

> *…The major difference between a research institute and an industrial research center is that people in the industrial research centers work hands-on close to the process line, while institute researchers take a generic approach. Thus, as an institute researcher you don’t develop a sensitivity of what you are actually working on. You direct your efforts at developing some sort of theory or equation or compare microstructures without developing a basic understanding of what this means out there in real life…*

The PROSMAT period, however, introduced a new era of joint collaborative efforts that redefined the traditional division of roles. Now the SINTEF researchers started to cooperate *directly* with both press plant workers and Hydro researchers. This shift enabled the emergence of better problem definitions and solutions. In the words of a SINTEF researcher:

> *…In contrast to the EXPOMAT period, we were now out at the press plants working on problems, getting first-hand knowledge of the problems. Because of this, we got a better understanding of how to attack the problem – or to put it another way**: In research, definition of the problem is decisive**…Asking the right questions in defining the problem is important for the subsequent approach to, and solution of, the problem. **Earlier, when people in Hydro’s in-house research groups filtered the problems, the definitions were based on their understanding of the problem. However, when we went to the plants ourselves, we could learn about the problem and contribute directly to the definition and solution of the problem. This way of working was important**…*(emphasis is mine)

Thus, the direct collaboration fostered fruitful *co-generative problem definition and problem solution*[406] increasing the collective capacity to succeed with the innovation efforts. In turn, this co-generative problem definition stimulated local commitment and interest in solving project tasks. As subproject manager Aukrust recounted:

> *…We traveled around to talk with people to get to know their understanding of the matter. Next, when we had discovered some things ourselves, we went back to present our understanding of things along with suggestions for methods of solution.*

[406] The phrase “co-generative” is inspired by Greenwood and Levin’s (1998) concept of co-generative learning and action research.

> *When they saw the potential benefit, and realized that our efforts could result in improvements, they became fully committed to our project…Thus, **without their understanding of our propositions or their recognition of the practical value, they would not have been willing to cooperate**…Our interest in solving their problems was met with an open attitude facilitating the accomplishment of practical experiments and manufacturing of test dies and such things… This goodwill was quite decisive…**Without it, things just stop**…*(emphasis is mine)

Furthermore, the "Bearing Channel" project shows that emphasis on *joint verification/validation of research results* encouraged information sharing between researchers and industrial people. It represented a sound working method combining "*the best of the academic world with practical industrial projects*", as a project member put it. Experimental work in press plants offered both groups valuable information. It provided SINTEF researchers with important hands-on experience and feedback on their results. At the same time, the researchers' systematic scientific approach made industrial people acquire knowledge about the impact of their work. Some recommendations for design and maintenance of dies were not new to die designers or die correctors. They "*were a matter of courses that everyone knew, but still didn't act on*," as a project member expressed it. Nevertheless, the systematic verification provided a powerful validation, forming the basis for a new, standardized practice. "*We were able to verify that this is actually a smart way of working*", the manager of one of the in-house Hydro projects stated, explaining:[407]

> *…The usual industrial practice is trial and error; often many parameters are changed simultaneously, meaning lots of results, but not necessarily answers…Moreover, there are the people who have worked in extrusion plants for about thirty years - who knows everything, who has tested out everything and therefore think they don't have to do things differently, throwing a spanner in every new suggestion. However, if you do it the proper structural way like we did in this project, changing one parameter at a time, documenting the actual effect and working out guidelines stating "this is the way to work," then such discussions end. Things are verified. That's that! In fact, until then I think the die correctors did not realize the real impact of their maintenance strategies; it would take very little to change geometrical characteristics…*

Information sharing between researchers and industrial workers was further stimulated through *frequent meetings*. Throughout the duration of the project the managers of the Hydro projects arranged regular *project workshops* at the press plants, as well as meetings with researchers only. At the workshops, project members discussed experiences and

[407] As discussed earlier, the "Bearing Channel" project was carried out in close collaboration with two in-house Hydro projects.

results of full-scale experiments with the die manufacturer and people in the press plant. These meetings also acted as sessions in which the participants practiced communication skills facilitating mutual exchange of knowledge. As one of the in-house project managers commented:

> *…At the workshops with press operators it was important to use a language they understood to make them feel they received something valuable in return for their engagement. I think we succeeded in these efforts. It made sense to them that we were present, talking and doing things. In fact, they had a number of "light bulb moments". Good communication was a great challenge for both the representatives of the press plant and those used to theoretical work and terminology. On the other side, I think exposure to a situation in which you have to explain and present matters to others in a way that makes sense to them, is useful because you need to understand the problems all the way. Actually, it's a way of becoming an even better researcher. You cannot hide behind equations and terminology; you really have to understand what you are communicating to others…*

Accordingly, the emphasis on sound information sharing gave the researchers the possibility to increase their *interpersonal* skills, a vital part of individual creativity (Ref. Chapter 8).

To boost progress, the in-house project managers also emphasized *proper documentation of the meetings*. Issues highlighted at plant meetings were taken under further consideration in researcher meetings to stimulate the "*conversion from the practical to the theoretical*," as a project member put it. Likewise, researchers presented their results and suggestions through addresses to die designers, die manufacturers, and press operators during the verification/validation period. After some time, Aukrust and his colleagues also joined one of the Hydro project managers at the annual meetings of the manufacturing managers in HAEX. Their presentations of research results on these occasions supported implementation of the recommendations for die maintenance and design within HAEX plants. Also, the active encouragement of one of HAEX top managers facilitated these efforts.[408]

Thus, to summarize, the "Bearing Channel" project shows that work forms and approaches encouraging direct communication and interaction between external researchers and industrial people (problem owners) in the latter's setting was a critical factor of success. Visits to industrial sites and direct collaboration between problem owners and external experts facilitated redundant information and assisted the "outsiders" in acquiring

[408] Ref. Chapters 8 and 9.2.

vital context-relevant skills. As such, these approaches, enabling sound co-generative problem definition and solution, provided far better problem definitions and solutions than the traditional “relay race” approaches
In turn, co-generative problem definition contributed to creating local commitment and interest in defining and solving critical project tasks, a necessary condition for implementation.

The “Empirical Modeling” Project

Similar to the other PROSMAT Extrusion projects, “Empirical Modeling” calls attention to the power of work methods and approaches facilitating a close direct interplay of external researchers and industrial “problem owners”. I illustrate this by giving a glimpse of activities in the pre-study period and by showing how a large meeting provided vital information increasing the likelihood of innovation success.

During the pre-study subproject manager Kavli and colleagues visited several extrusion plants, tool manufacturers, software suppliers, and research groups to discuss the idea of utilizing logged process data to obtain better extrusion process management. Based on the impressions from the visits and the discussions, Kavli prepared a pre-study report including a presentation of major project ideas, reflections on where research should be focused to gain improvements, and an evaluation and recommendation of project ideas.[409] Still, further discussions were needed to make decisions about specific applications. Therefore, Kavli and teammates went on, discussing possible applications with industrial people and academic research groups. They spent considerable time at press plants, establishing contact with people at various levels to learn about day-to-day practices and topics of industrial interest. Through these collaborative discussions prediction of press speed for new sections emerged as the main theme.

When Kavli and his teammates carried out analyses based on the early versions of the software in question, the results revealed large speed variations in the same die at all extrusion plants. These variations made the data less suitable for developing empirical models able to estimate process parameters and productivity for new sections. To identify the reasons for the variations, Kavli and colleagues arranged a large meeting at the press plant at Karmøy. They presented and discussed their findings with, among others, all the

[409] SINTEF REPORT No STF 72 F 96 618 1995-12-13 (restricted) New Modeling Techniques for the Future Extrusion Technology Empirical Modeling. Pre-Study Report.

press operators responsible for setting the process control parameters. The press operators recognized the variations, providing several explanations for the situations without being able to give a sound answer to the problem. Based on this response, Kavli recommended the initiation of an in-house HAEX project to work on the problem. At the same time, he and his colleagues concluded that the available process data and CAD drawings were not sufficient for building empirical models. They realized that they also had to make use of the operators' practical knowledge and experience.

So, to summarize, meetings and workshops at local sites made project members learn context-relevant skills helping them to make a proper contribution to the project. In addition, they provided important knowledge increasing the likelihood of innovation success. The work forms in question also enabled the creation of commitment to the "Empirical Modeling" project.[410] As a member of the steering committee stated:

> *…The fact that they entered the press plants, observing what actually happened, was a very important aspect. Implementation of research not based in the actual operation of daily production is likely to fail…*

The Omacor™ Project

When it comes to the Omacor™ project, the efforts directed at meeting the comprehensive requirements for therapeutic pharmaceuticals shed light on fruitful strategies enhancing information sharing and collective creativity. The requirements implied that Hydro researchers had to acquire context-relevant skills in terms of specialist competence on analyzing methods and procedures for documenting the quality of *k85*.[411] At the same time, lack of standardized analytical methods for omega-3 fatty acids added complexity to the matter, because different methods provided different results concerning the content of EPA and DHA. This situation was difficult, not least because it affected the image of omega-3 products. Therefore, Hydro researchers decided to commit themselves to the development of official, standardized methods of analysis.

To deal with the complex challenges, Harald Breivik, the project manager, established contact with external laboratories and specialists. One of the specialists involved was a professor at the Canadian Institute of Fisheries Technology. He was known as the world's foremost expert on marine oils. Breivik and his colleagues made several visits to the professor's laboratory to discuss relevant issues, to learn about his methods, to perform

[410] This observation implicitly points out the significance of *alignment* (Ref. Chapter 5.4.5)
[411] *K85* was the unofficial name of the 85% omega-3 concentrate that became Omacor™.

analyses, and to compare his methods with the methods used at the Hydro Research Center, Porsgrunn, and at other research laboratories. The Hydro researchers were also in close contact with a professor employed in the National Analytic Issues Service (NAIS) with the US Department of Commerce. She headed a laboratory that produced a substance similar to *k85* as a test substance for the National Institute of Health. The NAIS-work was public, providing access to critical process information such as complete laboratory journals for production and analysis of the concentrates, including a detailed description of processes. The Hydro researchers had several stays at the NAIS laboratory, studying journals and observing how the documentation efforts were carried out in practice. "*It was very important that we had access to the NAIS system*", Breivik said, remarking that the contact with the professors was decisive for the progress of the project. Among other things, the possibility to discuss diverse topics with leading experts made the Hydro researchers keep ahead of potential problems such as patent application issues and publicity on environmental pollution.

Furthermore, Hydro researchers arranged "Analysis Meetings" and inter-laboratory tests to deal with the problem of lacking standardized methods of analysis. These approaches have similarities with the parallel processing in the "Die Life" project. At the "Analysis Meetings" different specialists on analysis of marine oils and omega-3 fatty acids discussed and compared the different methods being used, hoping to develop procedures as similar as possible. The Hydro researchers also made contact with several laboratories worldwide to engage them in round-robin tests. The studies were followed by visits to laboratories where the researchers assessed the results and the competence issues. The Hydro researchers themselves were also invited to take part in such studies.

In sum, Hydro researchers' emphasis on field trips to leading competence groups, their close contact with leading experts, the "Analysis Meetings," and the inter-laboratory tests contributed to their success regarding the requirements of GMP and the development of official methods for analyzing omega-3 concentrates. The regular contact with the professors (and other world-leading experts) facilitated the acquisition of *context-relevant skills* required to meet the directions of GMP. In addition, it enabled fruitful professional reflections on current issues, increasing the researcher's capacity to deal with critical project tasks.

Pre-projects in the PROSMAT Extrusion Projects

All the PROSMAT Extrusion projects started with a pre-project aiming at defining clear, useful approaches to the problems.[412] Indeed, one had established subprojects on method development. Still, the areas of tangible improvements were not obvious in these projects characterized by long-term objectives and visions. As a consequence, questions such as "What cases should be worked on?" and "In what areas should the project contribute to success?" had to be investigated. Therefore, the main project manager emphasized the importance of spending some months making a thorough exploration of potential relevant approaches to the problems within the respective subprojects. As he remarked: "*Just sitting at your desk, defining a target is not easy. You have to work the matter through*!"

Participants regard the pre-project phase as a useful period contributing to bringing the subprojects into the "proper focus". As one of the subproject managers commented:

> …*Such studies are essential for focusing your efforts on a problem. Because you may always think of interesting ways of stating a problem, but they are not always fruitful...However, doing a thorough job aiming at a proper focus, that's important...*

The pre-projects made possible a thorough *problem definition* including investigations into areas of industrial application, evaluation of previous research, and discussion around working methods. In particular, the efforts were enhanced by the opportunities project members were given to arrange meetings and discussions with relevant research groups, Hydro managers, suppliers, and people in the extrusion plants.[413] These discussions contributed to giving the subprojects the proper focus.

Thus, pre-projects encouraging thorough co-generative problem definition were important, increasing the likelihood for innovation success.

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[412] At the actual time, the PROSMAT Extrusion pre-studies largely represented an innovation within the Hydro context. Based on the positive experiences in the PROSMAT Extrusion project, pre-projects have since become a regular, highly appreciated part of projects carried out within Hydro Aluminium Extrusion.

[413] As such, the PROSMAT Extrusion projects point out the beneficial effect of *resources* in the sense of time and money, another stimulant of creativity (Ref. Chapter 5.4) for pre-projects aimed at defining clear, useful approaches to the problems.

9.4.2 Discussion

In Chapter 9.4.1 I presented several examples of approaches and work forms boosting collective creativity, thereby increasing the likelihood for innovation success. I now shed further light on how these strategies promoted innovation.

When viewing the approaches and working methods presented above in light of Nonaka and Takeuchi (1995), it becomes evident that these strategies fostered collective knowledge creation, because they encouraged a dynamic interaction of tacit and explicit knowledge. The workshops and other face-to face meetings represented *social fields of interaction* triggering *socialization*. Socialization was necessary in order for collective knowledge creation to take place. For instance, Hydro researchers acquired important context-relevant skills through a master-apprentice dyad where study tours to internationally acknowledged laboratories allowed them to follow experts through daily work processes. Similarly, SINTEF researchers developed vital context-relevant skills through face-to-face meetings with practitioners and through “on the spot”-observations. Evidently, these learning strategies were beneficial. They provided SINTEF researchers with the opportunity to learn about essential industrial problems and get a proper understanding of the problem context.

Likely, the collective reflections and dialogues enabled by workshops and face-to-face meetings also stimulated *externalization*. For instance, the ”Die Life” workshop resulted in conceptual knowledge in the form of specific suggestions for die designs and plans of action. Similarly, practical follow-up of the suggestions through further work, practical testing, and verification evidently stimulated the modes of *combination* and *internalization*. Thus, the “Die Life” project indicated that emphasis on workshops/face-to-face meetings and subsequent practical follow-up stimulated all the four modes of knowledge conversions.

Yet, I do not believe that the knowledge creation followed the sequential determined order of knowledge creation proposed by Nonaka and Takeuchi (1995). That is, I do not think that the workshops and face-to-face meetings fostered socialization and externalization only, nor that practical follow-up solely encouraged combination and internalization. Taking account of Engeström’s (1999) findings, I assume that the various social interactions in the ”Die Life” project, as well as in the other case projects, implied different orders and combinations of tacit and explicit knowledge. My empirical data is not particularly fit for shedding light on this suggestion. Still, the case projects show that collective knowledge creation requires sharing of both tacit and explicit knowledge. In this connection, I think the concepts of *co-generative learning* (Greenwood and Levin, 1998), *organizational learning* (Argyris and Schön, 1996), and *reflective practice* (Schön, 1983) provide better explanations of the collective knowledge creation process than Nonaka and Takeuchi's (1995) attention to knowledge conversions.

Viewing my empirical data in light of Greenwood and Levin's (1998) *Co-Generative Action Research Model* (See Figure 9.4.1 below), I find that the various approaches and working methods facilitated collective knowledge creation by encouraging collective inquiry.

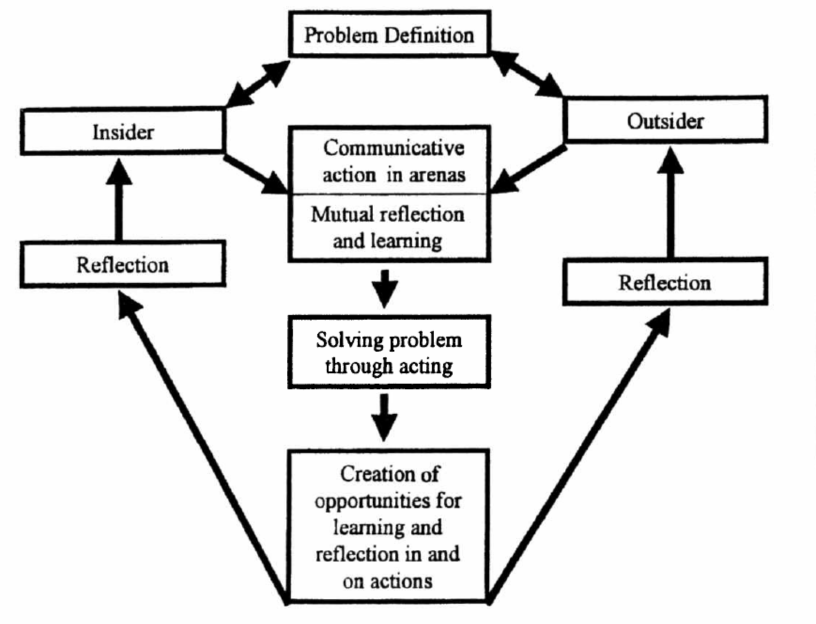


Figure 9.4.1 The co-generative learning model (Greenwood and Levin, 1998)

The "Analysis Meetings" in the Omacor™ project and the workshops and face-to-face meetings in the PROSMAT projects were *communication arenas* enabling mutual learning and reflection between *insiders* ("problem owners") and *outsiders* (professional researchers).[414] The arenas created space for the co-generation of new understanding guiding subsequent action. In particular, they boosted the creation of redundant context-relevant skills, an essential component of collective creativity. In this connection, the PROSMAT Extrusion pre-projects emphasize the importance of staging for co-generative *problem definition* at the outset of innovation projects (Ref. upper part of Figure 9.4.1). This initial co-learning process was vital since it permitted the development of a mutually

[414] Of course, the project role of the "outsiders" in the PROSMAT projects was different from the role of action researchers in Co-Generative Action Research projects. Yet, I think that the PROSMAT projects exemplify Greenwood and Levin's (1998) argument that the asymmetry in skills and knowledge can be an important force in co-generating new understandings.

agreed-upon problem focus facilitating the creation of commitment to the project. In addition, it allowed all participants to make the most of their expertise, and it made outsiders acquire vital context-relevant skills. As such, the co-generative problem definition increased the level of collective task-relevant skills, thereby boosting the collective capacity to solve pertinent problems for the industrial units in question.

Moreover, emphasis on problem solving through action and practical follow-up of the outcome of workshops/meetings created new experiences to reflect on for project members. In turn, new meetings/workshops implied that project members' reflective processes were fed back into the communicative process, shaping the areas for new dialogues aimed at either redefining the initial problem definition or improving the local problem solving capacity (ibid.). Thus, emphasis on repeated cycles of collective reflection and action implied that the approaches and work formed referred to created opportunities for collective learning and reflection in and on action, i.e. a collective *reflective practice* (Schön, 1983; Greenwood and Levin, 1998). In this connection, it is noteworthy that communication arenas may also stimulat co-generative learning by serving as communication training sessions, boosting the development of a mutually understandable discourse (Ref. the "Bearing Channel" project).

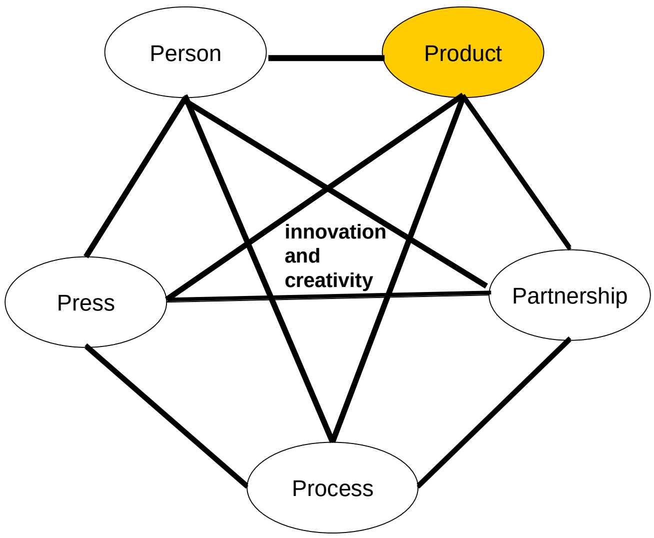
Furthermore, the Co-Generative Action Research model also illustrates the benefit of a parallel research-industrial processing strategy. The framework suggests that *parallel processing*, including regular coordination of activities, implies short feedback loops between insiders and outsiders. For instance, frequent mutual exchanges of results from FEM stress computations and practical testing in the "Die Life" project speeded up the co-generative process. This also applies to the verification efforts in the "Bearing Channel" project. Argyris and Schön (1996) provide a further explanation for this effect. First, frequent information sharing stimulated the collective learning capacity by providing the actors with fast feedback on their theories-in-use. In turn, this feedback enabled rapid single-and double-loop learning. Second, the diversity enabled by the involvement of insiders and outsiders facilitated double-loop learning (e.g. the idea behind the "New Die"). In this connection, the PROSMAT projects, and in particular the "Bearing Channel" project, illustrate Greenwood and Levin' (1998) argument that the asymmetry in skills and local knowledge can be an important force in the co-generation of new knowledge. For instance, the "Bearing Channel" project shows that the researchers' scientific approach to experimental work implied systematic testing and externalization of practitioners' theories-in-use; it made practitioners aware of the real impact of their maintenance strategies. In turn, this awareness facilitated implementation of the guidelines, enabling organizational learning to take place. Similarly, insiders contributed with critical local knowledge and relevant practical competence. The die experts' feedback on FEM stress analysis in the "Die Life" project is a striking example here. Thus, similar to Co-generative Action Research projects, the PROSMAT projects combined the *best efforts* of both local people and external researchers.

Summing up, I find that *approaches and work forms supporting co-generative learning and a collective reflective practice increase the likelihood of innovation success*. This implies the creation of *appropriate arenas for communication* (social fields of interaction). Such arenas allow socialization and communicative actions to take place among experts representing a great variety of competence. In particular, they boost the creation of redundant context-relevant skills, an essential component of collective creativity. My study shows that the following arenas are particularly useful: *face-to-face meetings and stays in the problem context*, *workshops, joint verification-/validation efforts*, and *informal master-apprentice dyads* enabled by visits to relevant expert groups. In addition, *pre-projects* aimed at thorough co-generative problem definition and *parallel processing* are fruitful strategies. Parallel processing boosts repeated cycles of collective reflection and action, thereby speeding up the overall progress of project efforts.

Chapter 10 Analysis and Discussion of the Product Facet of Innovation and Creativity

10.1 Introduction

In this chapter I analyze and discuss my empirical data in light of the *Product* facet of innovation and creativity. More specifically, I examine how project participants assess the outcome of the case projects in light of the concepts "radical" and "incremental" innovation in accordance with the facet-specific research question presented in Chapter 5.5 (see below).



Research Question in Terms of the Product Facet of Innovation and Creativity

How do project members assess the outcome of the project in light of the concepts incremental and radical innovation?

10.2 How Do Project Members Assess the Outcome of the Project in Light of the Concepts Incremental and Radical Innovation?

Reflecting on the innovativeness in the "Die Life" project, a professor in the PROSMAT Extrusion steering committee said:

> *…I regard the results as incremental. However, it may be that HAST staff members have a different view. This is because a tenfold increase in die life is not regarded as incremental. Even though the basic understanding was not changed, the effect of a small improvement was enormous. Nevertheless, the borders are quite unclear…*

The professor's statement reflects the very essence of this chapter. The case projects show that project members' assessments of project results reveal no clear agreement concerning degree of "radicalism". Evaluations of the New Die provide a prominent example here. About one third of the informants regard the New Die as an incremental innovation, while a similar number of persons think of it as radical.[415] A third group considers the innovativeness of the New Die to be halfway between incremental and radical innovation. The persons who regard the New Die as incremental innovation claim that nothing but an entirely new process technology could be considered "radical" innovation. A researcher at the HA R&D center, Karmøy, stated the reasons for his argument this way:

> *…We're already working with tools; die design represents nothing new. A new design is advantageous, of course. On the other hand, it's nothing extraordinary. The result remains the same; you still get an identical profile…*

Where this researcher emphasizes *absence* of novelty, a professor in the steering committee calls attention to the *nature* of the research process itself:

> *…The "long die life"-die is, as I've previously pointed out, incremental. They have had a stepwise approach, managing to make improvements all along. However, a radical innovation in this area would mean that the whole die is thrown away and substituted with something quite different that still produces the very same articles...*

Similarly, a HAST staff member commented:

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[415] For practical reasons, I here refer to the New Die, etc. as incremental or radical "innovations" even though the actual project results may not necessarily fulfill my requirements of "innovation" (Ref. Chapter 2.2). This is because informants often used the term "innovation" when referring to a particular project result.

> *…The extrusion process is an old process. Our present approach means that we're patching up an existing process. A radical innovation, in contrast, would imply rethinking the whole process, for instance, turning it into a continuous rather than a semi-continuous process. A radical innovation means that you start doing things in an entirely new way, initiating a new learning curve. However, in our case we're still on the same S-line. We've done things step by step. As a consequence, the result is incremental…*

Ergo, the informants independently agree that the New Die is an incremental innovation, arguing that it represents the continuous improvement of an existing process technology, enhancement of competence, and absence of novelty. As such, they base their judgments on several criteria usually associated with incremental innovation (Ref. Chapter 2.3, Table 2.3.1).

Speaking partly in line with the group of informants just referred to, others point out that the New Die displays both incremental and radical characteristics. "*It is neither incremental nor radical,*" a professor in the steering committee claimed. According to him, nothing but an entirely new process technology is radical innovation. At the same time, the basic design principle is different from previous ones, meaning the New Die is about more than incremental change. Arguing in line with the professor, a researcher at the HA R&D center at Karmøy, stated:

> *…The die design represents a change that is rather halfway between - perhaps a little more radical than incremental. After all, there were some new radical things that were introduced. Still, a great part of the die design is similar to the traditional design. The radical part was the basic design principle. Nevertheless, there are certainly other variants using the same principle. It's kind of giving the finishing touch to well-known techniques. Actually, the die design is radical. On the other side, I will not denote it as a clear "radical" innovation…*

The two latter informants agree that the New Die is not a radical innovation; it does not break with existing process technology. Rather the New Die is an improved version displaying many traditional characteristics. As such, the informants speak in line with the "incremental"-oriented informants who highlight the aspect of continuous improvement with respect to extrusion technology as a whole. Still, they do not consider the basic design principle as incremental: Its deviation from existing design principles is somewhat radical, at least something more than pure incremental change. For this reason, the New Die may be placed in the middle of the incremental-radical continuum. So, where the first group of informants refers to the context of extrusion technology as such, the "incremental-radical" informants refer to extrusion technology, *as well as* to the specific context of design principles. And: It is the attention to the latter frame of reference that makes the "incremental-radical" informants associate the New Die with a higher degree of "radicalism" than the "incremental"-oriented informants.

As opposed to the views presented so far, some project members do regard the New Die as a radical innovation: "*The New Die concept is close to a radical innovation, because it represents something quite new – entirely new*!" a HAST employee argued. Similarly, another HAST employee stated:

> *...This concept is radical. It's something we never have worked on before. We started producing profiles in 1966/1967, and I have never seen anything close to this...*

By pointing out newness to the business unit, the HAST employees indicate emphasis on a break with the past (i.e. discontinuity), a criterion usually associated with radical innovation (Ref. Chapter 2.3, Table 2.3.1). A researcher at the HA R&D center, Karmøy, argues in line with the HAST personnel. Defining innovation as "something relatively radical" in itself, he calls attention to the application of an existing principle in a new context. He said:

> *...The resulting design philosophy was innovative. The basic understanding of the problem was taken as a starting point. In addition, we applied a solution used in other contexts within other industries in a new context, and that's genuinely innovative...*

In contrast to the previous "radical" spokespersons, a SINTEF researcher points out the overall effect of the "Die Life" project:

> *...The PROSMAT results are radical because Hydro, and the Automotive division in particular, survives so incredibly well in a tough market. This seems to indicate that our contribution represents an important part of the profit, making survival possible...*

Thus, the informants who define the New Die as radical use different criteria when making their assessments: Novelty to the business unit; novelty with respect to the connection between idea and context; and commercial performance. As such, the informants' consensus on "radicalism" does not necessarily reflect consensual agreement on judgment criteria. This finding mirrors the variety of criteria of "radical innovation" found in the literature (Chapter 2.3).

Summing up, I observe that the New Die is subject to considerable disagreement when it comes to the degree of “radicalism”. The judgments of “radicalism” differ because informants call upon different criteria and referential material when making their assessments. Informants expressing similar views largely base their assessments on the same criteria. Yet, consensus on “radicalism” does not necessarily mean conformity when it comes to criteria of judgment.

The outcome of the “Bearing Channel” project is associated with both incremental and radical innovation. A professor in the steering committee argues that the development of modeling techniques was a matter of utilizing existing knowledge. Similarly, a researcher at the HA R&D center, Karmøy, claimed:

> *…The innovative degree of these things is really a subject for discussion…I think they are closer to the incremental side of the axis…*

In contrast, a SINTEF researcher associates the project outcome with radical innovation. According to him, the new method for experimental die studies[416] and the modeling of flow in the bearing channel represented entirely new approaches to research in the field of extrusion technology. In addition, they provided “a considerable leap forwards regarding understanding,” as he put it. Therefore, the researcher argued, the innovativeness of the FEM modeling and die studies is close to radical and clearly radical innovation, respectively. In other words, where the first group of informants emphasizes *absence* of novelty with respect to existing knowledge and past practice,[417] the SINTEF researcher calls attention to novelty. Where the former obviously notice small improvements only, the SINTEF researcher calls attention to the *break* with existing working methods and the following considerable increase of relevant knowledge. As such, the “Bearing Channel” project provides another example of the lack of consensual agreement surrounding informants’ assessment of the “radicalism” of project results.

The “Empirical Modeling” project is associated with a high degree of ”radicalism”. “*Although parts of it are relatively well-known things - the statistics are several hundred years old - the totality for our business was radically innovative*” a researcher at the HA R&D center, Karmøy, stated. The Speed Predictor and Shape Finder tools are seen as

[416] The researcher here referred to the study of the interaction between the section surface and bearing surface by opening up dies with the butt end (what is left of the billet in the die when the extrusion cycle is completed) still inside (Ref. Chapter 6.3.1).
[417] I do not know which particular context(s) the informants refer to. I therefore assume that they refer to both extrusion technology as a whole and to the specific business sector Hydro Aluminium Extrusion.

radically new products within Hydro Extrusion, representing "major steps forwards for the current state of the art in industry."[418] In particular, the software program for automatic analysis of section shapes from CAD drawings, founding the basis for both Die Finder and Shape Finder, is regarded as an "academic event" in terms of an entirely new method in the field. Thus, the results of "Empirical Modeling" are judged as "radically" new with respect to several frames of references: The business sector, the industrial field, and the academic field.

Still, the most striking finding about this project is that even though most project members perceive it as radical, people in the Research Council of Norway (RCN) expressed doubts about its innovativeness during the project period. In particular, they questioned whether the research objective and the project's degree of risk sufficiently satisfied the criteria for financial support: Is it research or is it development, e.g. is the project merely a consulting case where Hydro buys the knowledge for adaptation and application within the particular context? How risky and challenging is really this work of bringing the generic modeling knowledge into a new setting? A RCN representative remarked that this skepticism might largely result from the fact that RCN people were not familiar with the particular technology. As such, this representative highlights the issue of who are qualified to be appropriate judges in the field (Ref. Chapter 3). More interesting, though, is the observation that "internal" and "external" people make their assessments with reference to quite different criteria. Where the project participants themselves emphasize novelty, the RCN people indicate concern with other criteria used for separating incremental and radical innovation (e.g. degree of risk, and exploitation vs. exploration, ref. Chapter 2.3 and Table 2.3.1). The observation regarding variance of criteria of judgment reflects the findings from the other PROSMAT projects. At the same time, "Empirical Modeling" explicitly reveals the overall tendency that judgments of the "radicalism" of innovations are most often linked to novelty, degree of change, and impact of project results (appropriateness): In contrast to people in RCN, no project members point to dimensions such as risk or low predictability of outcome. As such, the "Empirical Modeling" project further illustrates the great interpretative flexibility regarding criteria of "radical" and "incremental" innovation.

When it comes to the Omacor™ project, project members associate the therapeutic pharmaceutical itself with an exceptionally large number of "innovative" properties. For

[418] PROSMAT: New Modelling Techniques for the Future Extrusion Technology. Project Report, 1999.

instance, Omacor™ is the first industrial (large-scale) omega-3 high-concentrate in the world, the first therapeutic pharmaceutical to be developed in Norway, and the first therapeutic pharmaceutical to be developed in Norsk Hydro.[419] For this reason, I expected project members to associate the project with high levels of "radicalism". Nevertheless, members of the Omacor™ project largely agree that the development of Omacor™ does *not* represent a "large inventive leap." Rather, it is a further stepwise development of common knowledge of omega-3 fatty acids and fish oil. In the words of a project member:

> *…The innovation here is the fact that we set about working on something already existing, managing to develop a well-documented therapeutic pharmaceutical product…*

At the same time, other project members suggest that the project may be seen as radical in the context of Hydro. A researcher at the Research Center in Porsgrunn said:

> *…In this context, we were involved in quite new things within the company. That may be considered as radical even though others were working on similar things…*

Similarly, another project member argued that the development of a multi-potent drug with several beneficial effects is somewhat radical because of its unusualness. Still, the two project members consider incremental change in terms of continuous improvement and competence enhancement as the most salient characteristic of the project. Thus, individual judgments of the "radicalism" of Omacor™ depend on the criteria and frames of reference in use: Omacor™ may be considered as a radical innovation with respect to Hydro, but as an incremental innovation in light of the wider context of omega-3 research.

Summing up, I conclude that the question *How do project members assess the outcome of the projects in light of the concepts incremental and radical innovation*? reveals no clear consensual agreement on innovativeness in light of the incremental-radical dimension of innovation. A specific innovation may be considered ”incremental”, ”partly incremental-partly radical", or ”radical" depending on what referential material individuals call upon when making their judgment. Individuals differ in their use of judgment criteria, frames of

[419] In addition, project members point out the following "innovative" properties of Omacor™:
1) Omacor™ is based on a natural raw material, which is highly unusual 2) Omacor™ is a multi-potent therapeutic pharmaceutical with several beneficial effects, which represents an even rarer case 3) Omacor™ is a well-documented product having passed the most rigorous testing program for omega-3 products ever 4) Contrary to other pharmaceutical products based on natural materials, the efficacy of Omacor™ is caused by its pure substance (the omega-3 fatty acids), not the original substance (fish oil) 5) Omacor™ has a surprisingly advantageous effect on several cardiovascular risk factors compared to lower concentrates 6) Omacor™ provides evidence for the beneficial effect of omega-3 fatty acids in the form of esters rather than triglycerides (the natural substance).

reference, and attention to factors such as the nature of the process, characteristics of the innovation, and the impact of the innovation. To some extent, people who agree on the "radicalism" of a specific project outcome propose similar reasoning. At the same time, agreement on innovation labels may display quite different foci in terms of criteria and frames of reference. Accordingly, my study reflects the great conceptual ambiguity revealed in the literature (Ref. Chapter 2.3), clearly demonstrating that labels such as "incremental" and "radical" innovation are subject to extensive interpretative flexibility (Pinch and Bijker, 1987). As such, it supports my assumption that a study of project participants' assessments of the projects' "radicalism" would reveal variance rather than consensus. For this reason, I also maintain that my decision to leave the explicit attention to "radical" innovation was reasonable.[420]

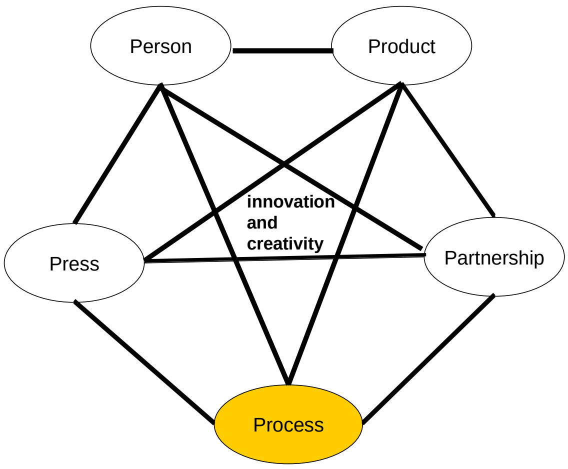
Most importantly, though, by demonstrating that innovation labels mean different things to different researchers and to the participants in the case projects, the study strongly indicates that these labels mean different things to other people as well. When viewing this indication in light of the claim that different kinds of innovation require different management approaches, it is evident that innovation managers should recognize the importance of collective reflections on innovation labels. No open-ended tasks can be successfully managed without emphasis on problem definition. This also applies to the visions of becoming "innovative" or staging for "radical" innovations. Accordingly, innovation managers should orchestrate discussions on relevant innovation labels, classification criteria, and frames of reference by calling attention to questions such as: What do we mean when we state that we aim to be "innovative"? When we say that we want to facilitate "radical innovations", what does this mean in practice? What characterizes "radical" innovations? Which classification criteria are important? Without such collective reflections, innovation labels can hardly be of any use when it comes to effective innovation management.

[420] None of the case projects appear as clear cases of "radical" innovation in terms of my consensual definition. Indeed, the "Empirical modeling" project may be defined as a case of radical innovation. Still, the observation that people in the Research Council of Norway expressed doubts of its very innovativeness makes me exercise caution regarding a clear conclusion here.

Chapter 11 Analysis and Discussion of the Process Facet of Innovation and Creativity

11.1 Introduction

In this chapter I analyze and discuss my empirical data in light of the *Process* facet of innovation and creativity. I structure the analysis according to the research questions proposed in Chapter 5.6, starting with the first sub-question (see below). Using the MIRP model[421] as an overall framework I examine the emergence and unfolding of "innovative ideas" during the initiation and development periods, respectively. Building on this inquiry I then highlight the question of how people collectively create new knowledge in highly ambiguous, uncertain, complex and uncontrollable situations (i.e. the second sub-question). Finally, I discuss the relationship between creativity and innovation in light of the main research question.



Research Questions in Terms of the Process Facet of Innovation and Creativity:

Is the need for creativity most prominent in the early period of innovation processes?

How do "innovative" ideas emerge and unfold over time?
How do people collectively create new knowledge in innovation projects?

[421] Van de Ven et al. (1999)

11.2 How Do "Innovative Ideas" Emerge and Unfold over Time?

11.2.1 The Initiation Period

As discussed in Chapter 5.6.2, the *initiation* period, which includes *gestation*, *shock*, and *plans*, is the period in which activities and events occur that provide the basis for launching innovation development (Ref. Van de Ven et al., 1999). *Gestation* is the long period in which "innovative" ideas emerge. Seemingly coincidental events take place, preceding and setting the stage for the initiation of innovations.[422]

My attention to how "innovative" ideas emerge and unfold over time immediately encounters the question of how the initiation periods of the case projects started: What was the very beginning of the initiation periods? Which event(s) serve(s) as the very origin of the gestation periods? Studying the projects I observe that clear answers to these questions are hard to reveal. Each project calls attention to several situations that may have acted as the point of departure for the gestation period. I illustrate this finding by using the Omacor™ project as an example.[423]

For the Omacor™ project the year 1951 stands out as a proper starting point for a review of the many situations representing possible starting point of the project. Until 1951, nitrogen fertilizers represented the only business area of Hydro. From this year onwards, the company expanded into Magnesium and PVC (1951), Oil and Gas (1965) and Aluminum (1967)[424], turning Hydro into a diversified company with separate business divisions. In the 1970s, PVC and fertilizers were considered "mature" businesses with limited potential for further growth, and international chemical industry turned the attention towards new business areas such as biotechnology. At this time, forecasts of an international protein[425] and food supply crisis made alternative sources of production a topic of great interest. Hydro entered into fish farming in 1969 and started a research program aimed at producing single-cell proteins from methanol in 1974. Competition from

[422] According to Van de Ven et al. (1999), *shocks* from sources internal or external to the organization trigger concentrated efforts to initiate innovations. *Plans* are instruments for obtaining the resources needed to launch innovation development. The plans are developed and submitted to resource controllers (See Chapter 5.6.2)

[423] Since this observation is not the main issue in this chapter, I briefly comment on the potential possible starting points of the PROSMAT Extrusion projects in footnotes later in this chapter. A comprehensive review of all the case projects with respect to the issue in question would take too much room at the expense of more important issues.

[424] "Norsk Hydro årsberetning 1992"

[425] Any of a large group of nitrogenous organic compounds that are essential constituents of living cells; consist of long strings of amino acids (source: www.dictionary.com)

traditional proteins proved to be strong, though, and the project was terminated in the late 1970s. Still, Hydro kept the focus on fine-chemicals, looking for alternatives to the single-cell proteins. The program "Fine-Chemicals from Biomass" was started in the early 1980s, bringing forth the competence acquired through the protein project. Initially, the potential of enzymes[426] from micro-organisms was explored, resulting in the development of two industrial enzymes at The Hydro Research Center, Porsgrunn. However, concluding that competition from the established enzyme business would be considerable, Hydro aimed at finding a Norwegian specialty with a competitive advantage. The obvious object of interest appeared to be *marine* biomass, and especially fish waste that was a cheap raw material. Research on fine-chemicals from fish waste was started in collaboration with The Fisheries Research Center, Tromsø, and The University of Bergen. One project aimed at developing a process for extracting enzymes from fish waste. The process resulted in both enzymes and a fatty by-product "that we constantly had to make an effort to get rid off", as the project manager expressed himself.

The emergence of the "problematic" fat raised the question of what to do with it. Dumping was no favorable solution, bringing the idea of a commercial utilization into focus. In 1984 contact was made with The Hydro Research Center in Porsgrunn. Among other things, the potential for the development of a therapeutic pharmaceutical based on omega-3 fatty acids was discussed. During the fall of 1984, preliminary research was started at the Research Center to explore the issue in further detail.[427] The research project, entitled "Fine Chemicals from Fish Waste", was formally started on January 1, 1985.

Indeed, the research project aimed at developing a process for extracting enzymes from fish waste stands out as a starting point of the gestation period of the Omacor™ project. This was the project in which the very fish fat appeared. At the same time, this research project emerged from Norsk Hydro's attention to fine-chemicals from *marine biomass* that, in turn, spun off the broader focus on fine chemicals from *biomass*. Clearly, the conclusion regarding industrial enzymes influenced Hydro's decision to look for a competitive Norwegian specialty, bringing *marine* biomass and fish waste into focus. As such, the initiation of the research programs on fine-chemicals from *biomass* and *marine biomass*, respectively, represent possible starting points for the gestation period. On the other hand, the very source of Hydro's interest in *fine-chemicals* as such came forth from the strategic

[426] Any of numerous proteins or conjugated proteins produced by living organisms and functioning as biochemical catalysts (source: www.dictionary.com)
[427] "Finkjemikalier fra fiskeavfall. Vurderinger ved start av prosjekt i Analytisk avdeling". 1984-11-22

discussions in the 1970s when PVC and fertilizers were considered “mature” businesses. For this reason, Hydro’s attention to new business areas (e.g. biotechnology) and alternative sources of production, reflected in the company’s entrance into fish farming and initiation of the “single-cell protein” research program, is another potential origin of the gestation period. Similarly, the termination of the “single-cell proteins” research represents another possible start of the gestation period of the Omacor™ project. Likely, if this research program had not been terminated, Hydro would not have decided to look for alternatives to the single-proteins, suggesting that the program “Fine Chemicals from Biomass” would not have been initiated. If this research program had not been started, Hydro would probably not have directed their attention to *marine* biomass and fish waste (as discussed earlier), meaning the “problematic” fish fat would not have appeared. As indicated earlier, the research program on fine chemicals from *marine* biomass (fish waste) stands out as another potential source of the Omacor™ project. In fact, also the appearance of the “problematic” fish fat itself may be regarded as a potential origin of the Omacor™ project. Accordingly, there is a multitude of possible beginnings of the initiation period of the Omacor™ project.

Summing up, I conclude that it is difficult to define the very beginning of the Omacor™ project. This conclusion also applies to the other case projects (see footnotes later in this chapter). The projects reveal the possibility of several different starting points, indicating *interpretative flexibility* (Pinch and Bijker, 1987). Evidently, the case projects are in the middle of things, in the middle of an ongoing flow of activities (Weick, 1995). The projects neither have clear starts, nor clear ends. It follows that defining beginnings is a social constructivist process; it is a *problem setting* process in which we cut particular moments out of a continuous flow, naming them the “beginning” and framing the context in which we will attend to them (Schön, 1983; Weick, 1995). Therefore, to facilitate the study of the case projects’ initiation periods, I simply have to define *one* of the possible beginnings as the origin of the gestation period.

Which of the possibilities outlined serves as the most appropriate origin of the Omacor™ project? Clearly, a perspective in which the strategic decisions in the 1970s are taken as the starting point, fully accounts for Norsk Hydro’s interest in fine chemicals as such. From a pragmatic point of view, however, the research program on fine-chemicals from fish waste appears as an appropriate beginning for the project’s gestation period. Therefore, I define the latter alternative as the starting point of the Omacor™ project.

The Omacor™ Project

Figure 11.2.1 illustrates the initiation period (gestation period in green) of the Omacor™ project.

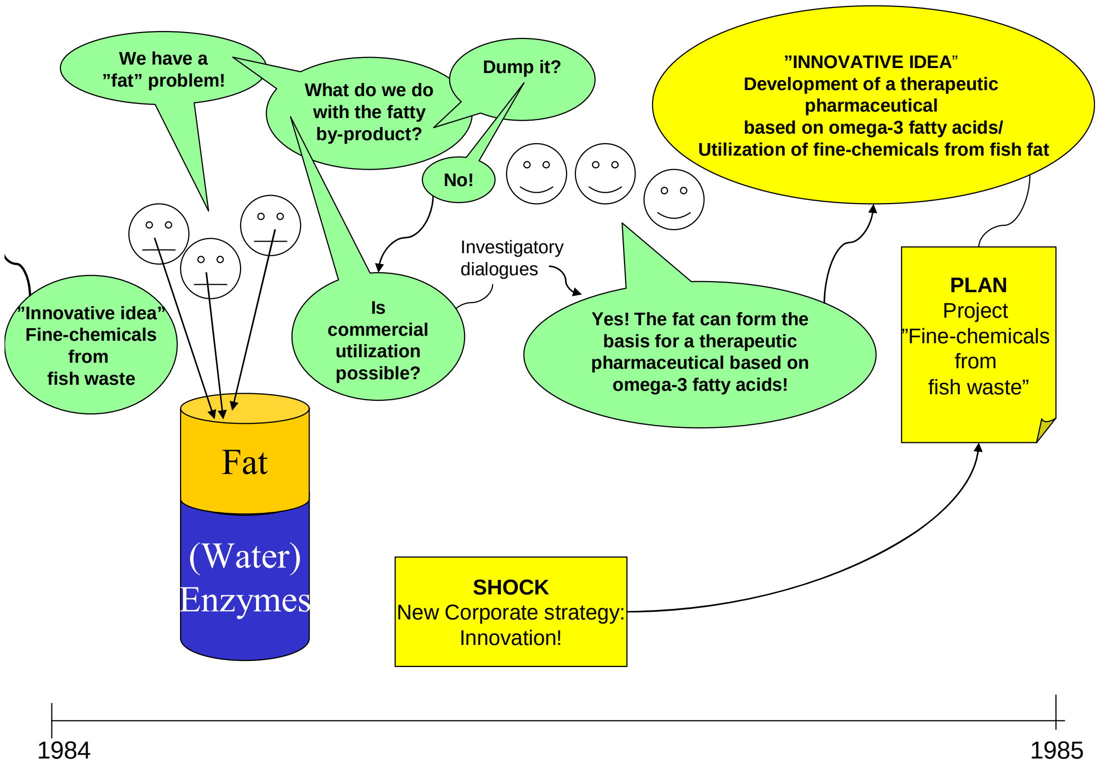


Figure 11.2.1 The Initiation Period of the Omacor™ Project

The source of the Omacor project™ was a research program on fine-chemicals from fish waste initiated by Norsk Hydro, The Fisheries Research Center, and the University of Bergen in the early 1980s. One of the projects aimed at developing a process for extracting enzymes from fish waste. The process was based on fish ensilage, implying storage of fish waste in large silo tanks at specific production parameters. During storage the fish "digested itself", providing a water phase containing enzymes and a fatty by-product on top. The emergence of the "problematic" fat raised the question of what to do with it (See Figure 11.2.1). Dumping was not a favorable alternative, bringing the idea of commercial utilization into focus. The project manager Sigurd Gulbrandsen and his colleagues applied to Norwegian biochemical research groups to discuss the potential of this marine biomass. A number of people representing different areas of expertise took part in these discussions. Gulbrandsen also contacted Bernt Børretzen, a researcher he knew at the Norsk Hydro Research Center in Porsgrunn, asking him if the fat could be exploited. Børretzen responded immediately, suggesting that the omega-3 fatty acids in the fat could form the basis for a high-concentrate omega-3 "heart medicine". He argued that the use of omega-3 for medical treatment was a new and expanding field with great potential. Gulbrandsen wrote a document on fine chemicals from fish waste, reporting that the unsaturated marine fat had properties that could be made use of in therapeutic pharmaceuticals. He also called attention to another group of fatty compounds that could be used in fish food.[428]

Gulbrandsen's report indicates that it is not easy to define one clear "innovative" idea that set the stage for the Omacor™ project. From one point of view, the idea of developing a therapeutic pharmaceutical based on omega-3 fatty acids could be regarded as "the innovative idea". From another point of view, the broader suggestion of a commercial utilization of the fish fat based on exploration of the raw material may be considered to be the innovative idea (see Figure 11.2.1). Yet, it is evident that the idea of a "heart medicine" acted as an effective "sales" vehicle towards top management.[429] As such, the project manager's report represented a *plan* (Ref. Van de Ven et al., 1999) developed and submitted to resource controllers to obtain the resources needed to make a further exploration of the commercial potential of the fish waste.

When it comes to the concept of *shock* (ibid), I define Norsk Hydro's new corporate strategy as the shock that stimulated concentrated efforts to initiate a project to explore the commercial potential of the fish fat (see Figure 11.2.1). The Corporate President, having entered into his position some months before, had immediately brought innovation into focus. Not only that, at that time, pharmacy was a "hot" business area, subject to great interest in Hydro. So, when Gulbrandsen and Børretzen presented the idea to top management in 1984, it was well received. In fact, several top managers were really excited about the idea. According to one of the seniors in top management, Norsk Hydro had always intended to enter into pharmacy, but the expansions into light metals, PVC, etc. had interrupted these plans. For this reason, the proposal of a project directed at exploring fine chemicals from fish waste fit well with the visions of top managers. The profits in the pharmaceutical industry were twice as large as in other industrial areas. In addition, Norsk Hydro was in a beneficial position, because there were no other large pharmaceutical companies in Norway. Several project members regard this situation as decisive for turning the project idea into reality.

At The Norsk Hydro Research Center in Porsgrunn, Børretzen started to look for a co-worker. He got in touch with Harald Breivik in the Analytical Department who found the

[428] Finkjemikalier fra fiskeavfall. Vurderinger ved start av prosjekt i Analytisk avdeling. 1984-11-22
[429] I shed further light on this below

idea highly interesting. In August 1984 the project idea was discussed at a meeting where, among others, the head of the Analytical Department took part. He was very excited by the idea of involving the department, generally perceived as a service organization, in the project. As a consequence, contrary to the usual practice, Breivik was allowed to start preparing the project even though they had no budget for it at that time. During the fall of 1984, Breivik joined Gulbrandsen and one of his colleagues for a visit to The Fisheries Research Center. Breivik was introduced to the ensilage technology, and he discussed the question of which types of fine chemicals were present in the fish fat with members of the ongoing research project. During the fall Breivik also made some chemical analyses and prepared for the start-up of the project. He wrote a status report in November 1984 with a proposed plan for progress and scheduled steps for the research that was to begin in January 1985. As such, the initiation period of the Omacor™ project came to an end.

The "Die Life" Project

The initiation period of the "Die Life" project started in the mid-1980s with a customer request for stronger bumper beams.[430] Until then, extrusion of open profiles followed by a welding operation had been the basis for the production of bumper beams at Raufoss Automotive. The welding operation was expensive, and extrusion of hollow profiles in AA7000 alloys appeared to be a better alternative than the preceding two-step process. Raufoss Automotive initiated a pilot project including, among other things, crash tests. The tests proved to be a great success, and extrusion of bumper beams (and other profiles) in AA7000 alloys became a "customer demand." Nevertheless, the new production proved to be a costly and difficult process because of severe technical problems with the dies: "*It turned out that these dies had a catastrophically short die life. The costs per kilogram of the profiles were astronomic*!" a HAST employee stated. The situation was critical, requiring rapid problem solving.

[430] I define the customer request for stronger bumper beams as the source of the PROSMAT "Die Life" project. The reason is that this request, causing severe technical problems, brought the very issue of die life into focus (as discussed in the coming main section). On the other hand, the PROSMAT "Die Life" project was a continuation of research in the foregoing EXPOMAT program and in-house Raufoss Automotive projects (Ref. Chapter 6.2). The EXPOMAT "extrusion" projects were based on the innovative idea of using FEM modeling techniques in the field of aluminum extrusion. Clearly, the experience with FEM modeling in the EXPOMAT "Die Life" project strongly influenced the proposal of similar activities in the subsequent PROSMAT "Die Life" project. As such, the innovative EXPOMAT "extrusion" project idea represents another possible starting point for the PROSMAT "Die Life" project. Still, the idea of using numerical simulations in the field of aluminum extrusion emerged from an earlier gestation period leading up to the application for participation in the EXPOMAT program. In this connection, the severe problems with short die life times due to the customer request played a decisive role. For this reason, I choose to regard the entire period from the customer request for stronger bumper beams (mid-1980s) to the formal start-up of the PROSMAT "Die Life" project as the initiation period of the PROSMAT "Die Life" project.

Another HAST employee commented:

> *…our new production obligation might result in severe economical problems for the company. Therefore, we needed to solve the problems as fast as possible. There was no time to lose. We were in the middle of a blaze…because our owner, Raufoss Automotive, was very impatient. We had made estimations of the profile costs that, naturally enough, did not add up right. The costs were far beyond the estimates, and we had to find a solution…So, it was an emergency situation. On the other hand, without this pressure, things take twice as long time. Unfortunately, we see that large inventions emerge in war-time situations – without comparisons…*

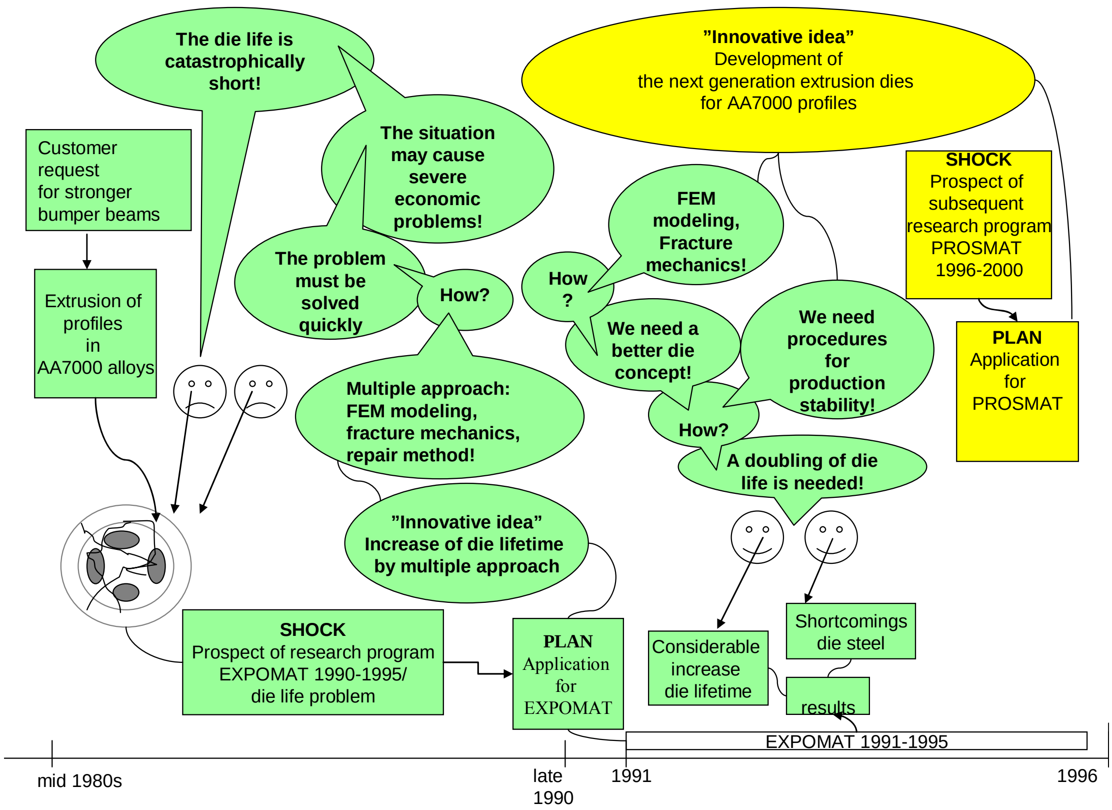


Figure 11.2.2 The Initiation Period of the "Die Life" Project

Sigurd Rystad, one of the seniors in the company, was given the responsibility for organizing project activities dedicated to the problem. He found that the acute situation required multiple approaches, where different ideas were tested in parallel. This approach meant involving external research groups. Rystad made contact with SINTEF Materials Technology where he had a network of acquaintances. He engaged material technologists to do fracture mechanics investigations of "damaged" dies to find out where and why cracks appeared. He also made contact with SINTEF Industrial Mathematics to involve people with numerical modeling competence. He assumed that numerical simulations were vital for solving the die life problems. At the same time, Rystad planned an in-house project aimed at developing a method for repairing the dies to increase die life.

The idea of increasing the die life by means of multiple approaches may be regarded as the innovative idea of the coming EXPOMAT project (see Figure 11.2.2). Likewise, the prospect of the five-year EXPOMAT research program may be seen as a coincidental fortunate "shock," facilitating the obtainment of necessary resources to engage external research groups (see Figure 11.2.2). At the same time, it is evident that the die life problem itself was a shocking incident that stimulated Raufoss Automotive into acting in the first place. Yet, for the time being, I regard the prospect of the EXPOMAT program as the "shock."

The application for an EXPOMAT project (the *plan*, ref. Figure 11.2.2) was approved, and the formal project activities were started in January of 1991. Through the EXPOMAT period important results were obtained, contributing to a considerable increase in die life. The FEM computations provided suggestions for optimized designs, and the repair method gave significant prolongation of die life. Nevertheless, increased competition from the steel industry meant that Raufoss Automotive had to make further improvements in order to survive as a manufacturer of aluminum bumper beams. An additional doubling of die life was seen as a prerequisite for competing with bumper beams made of high-strength steel. The development of a new die concept whose geometrical characteristics implied a further reduction of stress in critical areas was deemed necessary. In addition, crack investigations had revealed a number of serious shortcomings in the die steel due to sloppy procedures in the die shop. Accordingly, procedures for production stability and production control had to be worked out. Rystad and colleagues agreed that more fundamental research was needed to achieve the desired die life.

The prospect of a subsequent research program, PROSMAT, acted as a *shock* resulting in the proposal for a PROSMAT project (see Figure 11.2.2). The Raufoss Automotive people wanted to continue the established collaboration with the SINTEF departments in Trondheim, and they proposed the continuation of the "die life" research within PROSMAT Extrusion (the *plan*). The subproject was called Strength Calculations and Fracture Mechanics and was formally started on January 1, 1996. The project objective was "to develop the next generation extrusion dies for hollow sections in AA7000 alloys by the use of advanced calculation methods and knowledge in university groups."[431] Evidently,

[431] PROSMAT Extrusion. New Modelling Techniques for the Future Extrusion Technology. Project proposal, 1995-11-14.

the innovative EXPOMAT idea (increase of die lifetime by multiple approach, see Figure 11.2.2) had proved to be a sound one, and the succeeding innovative PROSMAT idea embodied the original idea. Yet, where the former idea was largely an answer to solving an acute crisis, the latter put emphasis on obtaining a favorable competitive position in the future: To develop the next generation of extrusion dies for AA7000 profiles.

The "Bearing Channel" Project

The origin of the "Bearing Channel" project, which started as two separate subprojects, was the formal start-up of the previous EXPOMAT extrusion projects.[432] During EXPOMAT, researchers at the Norsk Hydro R&D center at Karmøy and SINTEF directed their efforts at developing proper 2D and 3D FEM models for the extrusion process. The methods developed in EXPOMAT provided descriptions of the extrusion process *up to* the outlet where the section leaves the die. Still, the models could not predict the material flow in the so-called bearing channel, i.e. the surface along which the aluminum flows and is shaped (see Figure 11.2.3).

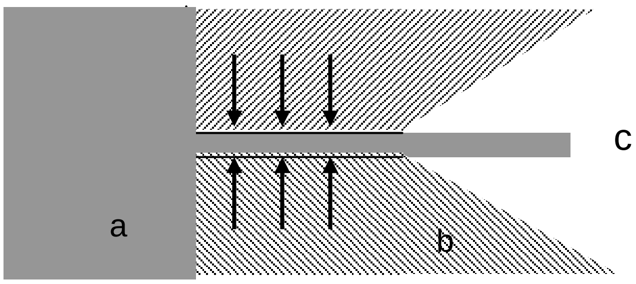


Figure 11.2.3 The Bearing Channel (a: Billet; b: Die; c: Extruded Profile)

For instance, predictions of a section's movement after the outlet, that is, if it moves straight on or turns away from its original course, could not be made.

The prospect of the subsequent PROSMAT program seems to have acted as a shock encouraging efforts to discuss ideas for further research (see Figure 11.2.4).

[432] As indicated earlier, the PROSMAT Extrusion projects were a continuation of the foregoing EXPOMAT Extrusion projects. I define the formal start-up of the EXPOMAT extrusion projects as the source of the PROSMAT Extrusion "Bearing Channel" project. Still, the gestation period of the EXPOMAT extrusion projects, as well as events taking place during EXPOMAT Extrusion, may be considered as other potential beginnings. I have no data on the first alternative. Still, it is evident that the innovative ideas of the two subprojects that were merged into the "Bearing Channel" project, emerged from the attention to FEM modeling as such (the "innovative EXPOMAT Extrusion project idea") and discussions on project results obtained during EXPOMAT Extrusion. Therefore, I find it appropriate to regard the initiation of the EXPOMAT extrusion projects as the start of the gestation period of the PROSMAT "Bearing Channel" project.

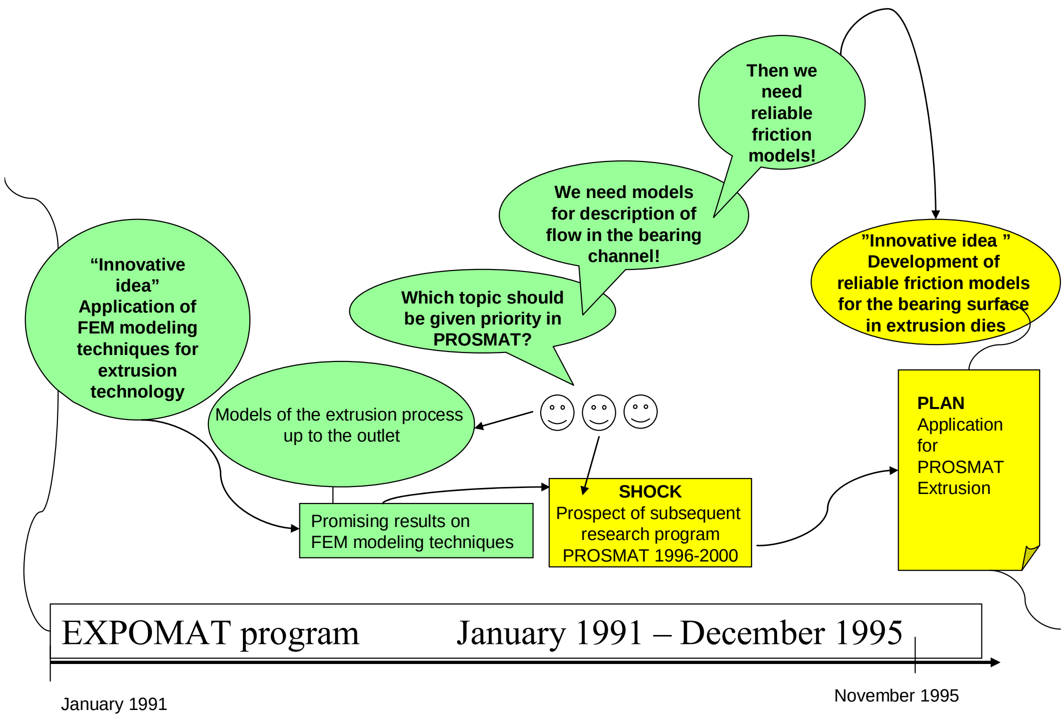


Figure 11.2.4 The Initiation Period of the "Bearing Channel" Project Part 1: Initiation of "Modeling of Friction".

The researchers knew that problems in the bearing channel could lead to improper flow balance that, in turn, could create various defects. Modeling of flow in this region was thus vital for meeting ever-increasing customer demands for closer tolerances and better surface quality. Therefore, application of simulation models for prediction of the material flow through an extrusion die was considered as an important tool for the development of future die design. This suggestion led to the question of relevant approaches. At that time there were several limitations to what could be simulated.[433] The description and modeling of friction in the bearing channel was one limitation. So far, researchers had used simplified friction models only. These models worked for 2D problems only and represented an undesirably long processing time. Thus, the innovative idea in "Modeling of Friction" was to develop reliable and effective friction models to obtain faster and more accurate predictions of the material flow in the bearing channel. Since the development of friction models was just a *means* for modeling of flow, "Modeling of Friction" was considered as a short-time project to be run during the first part of the PROSMAT period only. The project was formally started on January 1, 1996.

Similar to the "Modeling of Friction" project, "Modeling of Properties" was stimulated by the prospect of the coming PROSMAT program (see Figure 11.2.5).

[433] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Project Agreement 1997-03-11

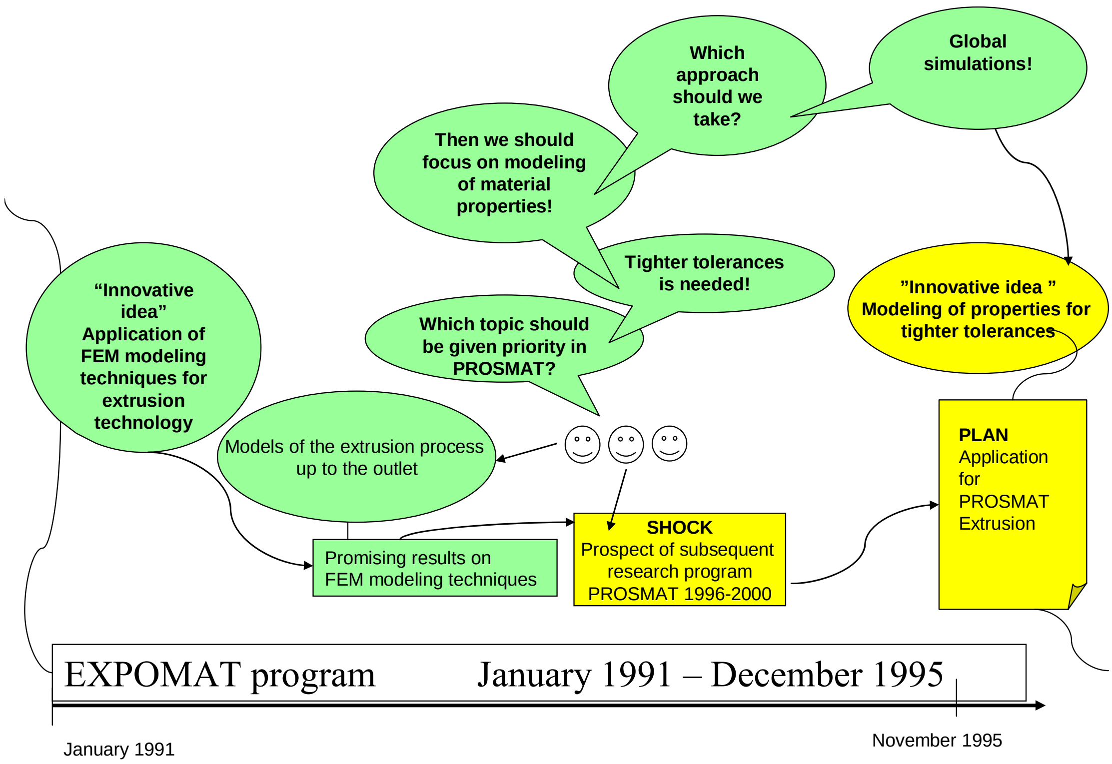


Figure 11.2.5 The Initiation Period of the "Bearing channel" Project Part 2: Initiation of "Modeling of Properties"

This "shock" encouraged EXPOMAT project members and HAEX people to develop ideas for further research. A major event was a brainstorming session held at the leading European press plant. Here a professor in the EXPOMAT steering committee, a HAEX manager, and others discussed project ideas with local project managers. The managing director spoke in favor of a vision of "zero tolerances" for aluminum extrusion. According to him, the goal for the extrusion process should be an improvement in the accuracy of profile wall thickness, from tenth of a millimeter to not more than micrometers. Following up on the idea, the professor proposed that the modeling of material properties should be emphasized. Better properties were a prerequisite for obtaining tighter tolerances for both geometry/shape parameters and properties, such as strength. He also suggested that *global simulations*, i.e. comprehensive simulations including the modeling of material flow, die deflection, etc. was necessary in this case.

Trond Aukrust, a SINTEF researcher who had been engaged in EXPOMAT to study the impact of a particular parameter on profile surface quality, proposed a similar idea. He knew that this parameter influenced other features, such as material properties, as well. For this reason, he regarded a project emphasizing material properties as a sound continuation of ongoing research. Thus, the "innovative idea" was to model properties in order to obtain tighter tolerances, in particular less variation in the strength of extruded sections (see Figure 11.2.5). The industrial target of "Modeling of Properties" was to improve the capability of the extrusion process so that the present variations in strength of extruded sections were reduced by more than 50 percent. The technical target was to provide predictions for how process parameters affected the final properties of the product. The formal project activities were started on January 1, 1996.

The "Empirical Modeling" Project

The gestation period of "Empirical Modeling" began with the formal initiation of the EXPOMAT program and thus the innovative idea of applying FEM modeling techniques for extrusion technology (See Figure 11.2.6 below).[434]

According to the main project manager of the EXPOMAT Extrusion projects, these projects were the first projects emphasizing FEM modeling as a tool. Testing ideas and learning from the results came first; direct applications came second. The projects revealed great opportunities for further progress and application of modeling techniques to increase extrusion productivity. The project activities also generated "lots of thoughts and ideas," the project manager commented. During EXPOMAT he regularly discussed ideas with one of the managers in Hydro Aluminium Extrusion. Among other things, they reflected on the observation that huge amounts of empirical process data was generated during press runs and then stored in process databases (see Figure 11.2.6). The project manager explained:

> *…Norsk Hydro has about 100 extrusion plants...During extrusion a lot of data is logged. Temperature, press speed, and forces related to different dies are some of these categories. However, the data was not made further use of…No one used historical data…*

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[434] I define the formal start-up of EXPOMAT Extrusion, including the innovative idea of using FEM modeling techniques in the field of aluminum extrusion, as the origin of "Empirical Modeling". The innovative project idea brought the very issue of modeling techniques into focus. From another point of view, this idea emerged from an earlier gestation period leading up to the application for participation in the EXPOMAT program. Accordingly, the start of *this* period could equally well represent the beginning of "Empirical Modeling". Yet, I have little empirical data on this gestation period, meaning the "innovative EXPOMAT idea" so far exemplifies the most obvious start for "Empirical modeling". From a third point of view, the idea of utilizing the large amount of process data logged at extrusion presses to predict and optimize process parameters (Ref. Chapter 6.4), may be defined as the beginning. Yet, *I choose to define the "innovative EXPOMAT idea", or more specifically, the formal start of the EXPOMAT program, as the very start of the gestation period of "Empirical Modeling"*. This is because I have little empirical data on the preceding initiation period, and because the attention to empirical models obviously emerged from the ongoing emphasis on modeling techniques for extrusion technology, as will be discussed in the main section.

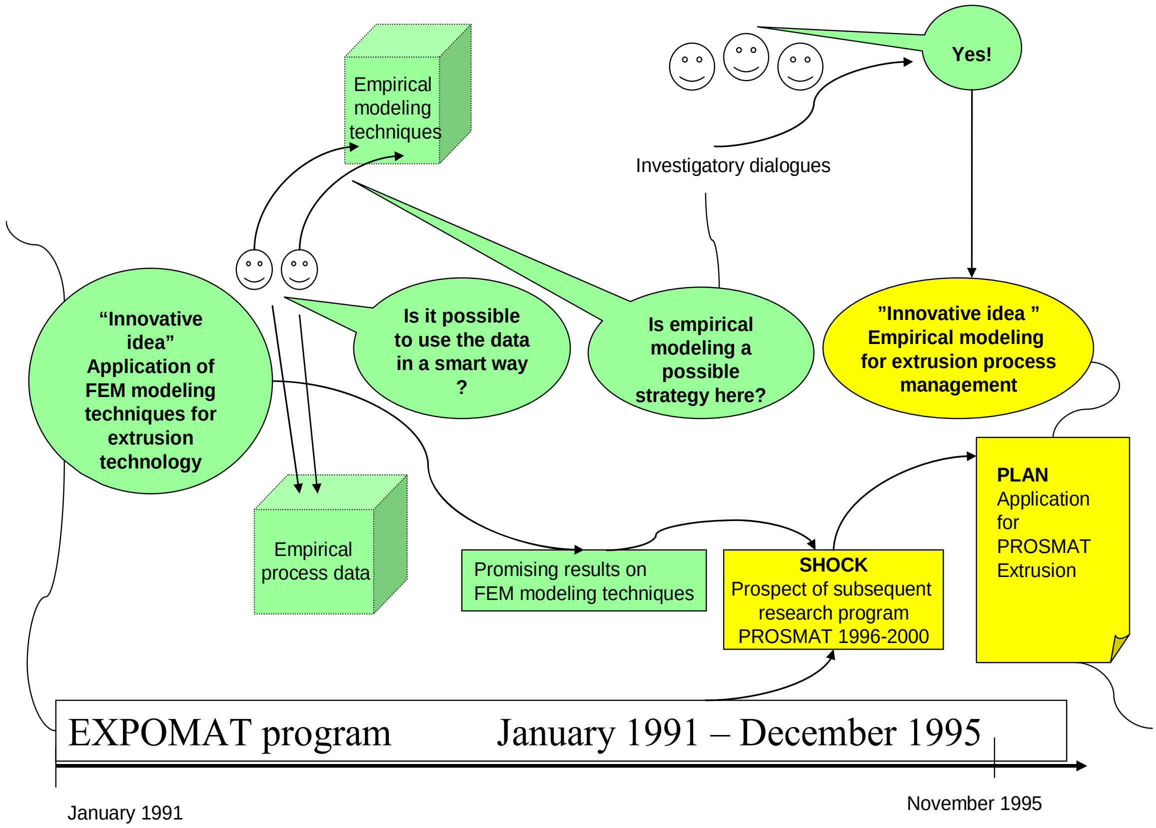

Figure 11.2.6 The Initiation Period of "Empirical Modeling"

This recognition triggered the questions: "Is it possible to use this data in a smart way?" "Could the process information stored in databases and files for CAD drawings be used to learn about the process?" (see Figure 11.2.6) The Hydro managers had also learned about some new modeling techniques that seemed to fit in exactly with their idea of making use of empirical process data. One technique was the so-called *fuzzy logic*[435] technique, a sort of self-learning computer system used in process control within other process industries at that time. "May this technique be applied within our field to obtain better process stability and productivity?" the Hydro managers asked. In particular, they wondered if empirical models could serve as an alternative to the FEM models that had been developed for the extrusion process. So far, these models had not been subject to industrial application due to their great complexity and long simulation time. They had been used to study greatly

[435] Fuzzy logic is a form of algebra employing a range of values from "true" to "false" that is used in decision-making with imprecise data, as in artificial intelligence systems. Source: www.dictionary.com

simplified problems only. Hence, Hydro managers found that there was a need for simpler models describing dependencies and relations between involved parameters without involving all the internal mechanics of the process. They kept pondering the question of whether empirical modeling was a possible strategy here (see Figure 11.2.6).

The Hydro managers discussed the idea with several people, and among those a SINTEF researcher who was engaged with EXPOMAT. During a conference, the project manager and the SINTEF researcher had a long professional conversation elaborating on the issue. The project manager learned that the SINTEF researcher, due to the joint location of several SINTEF departments in Oslo, was acquainted with colleagues working on empirical modeling methods. The SINTEF researcher offered to introduce the idea to people at SINTEF Electronics and Cybernetics. These researchers found it highly interesting. At the same time, the project manager and colleagues at the Hydro Aluminium R&D Center, Karmøy, were curious to find out about the methods the relevant SINTEF researchers were working on. They arranged an initial meeting with a SINTEF researcher to learn about the methods. Next, several SINTEF researchers were invited to the R&D center to give a lecture and discuss possible applications of the methods within the field of extrusion. This meeting was the first of several similar gatherings taking place during 1994/1995. The joint reflections, described as a "ripening process," encouraged the belief held by Hydro personnel that the idea of using empirical modeling for extrusion process management was worth pursuing.

The Research Council of Norway's decision to launch a new five-year user-led research program acted as a *shock* stimulating concentrated efforts to develop the idea into a *plan* (see Figure 11.2.6). The Hydro managers prepared a project proposal and filed an application with the research council. Thus, the idea of using empirical modeling for extrusion process management was the innovative idea setting the stage for the "Empirical Modeling" project.

Further Analysis and Discussion

In sum, the initiation periods of the case projects reveal several interesting findings. First, the case projects support the MIRP researchers' finding (Van de Ven et al., 1999) that innovations are not initiated on the spur of the moment by a single entrepreneur. The most striking feature of the initiation period for the case projects is that the "innovative ideas" emerged from an ongoing dialogue and reflection involving several people. For instance, the source of the idea of implementing empirical models was found in the regular discussions two Hydro managers had during the EXPOMAT period. When considering the idea of using empirical modeling, they presented the idea to several other people, among them a SINTEF researcher who introduced the idea to a relevant research group. Then followed joint reflections through meetings and lectures, acting as a “ripening process” making clear that the idea of implementing empirical models was worth pursuing. Similarly, the Omacor™ project shows that the “innovative” idea came forth from dialogues among several people. The project manager of the “enzyme from fish waste” -project introduced the idea of commercial utilization to biochemical research groups and to the Hydro researcher who suggested the fat could become a heart medicine. In turn, this contact triggered meetings and discussions between several people at the Research Center, visits to relevant research groups, and discussions of the idea with corporate top management. Thus, my data shows that *the “innovative idea” for an innovation project is born in a collective reflection involving several people*.

Second, I have already called attention to the fact that “beginnings” are a matter of interpretative flexibility. It is not possible to single out *one* clear starting point for the gestation periods. As such, the events or situations serving as “beginnings” in the above outline are simply moments that I have taken out of an ongoing flow of activities. This also applies to the incidents I have named “shocks” in accordance with the MIRP framework. For instance, I defined the prospect for the EXPOMAT program as the “shock” boosting efforts to solve the die life problem. Yet, I intuitively regard the die life problem as a bigger shock than the prospect in question, which instead may be considered a happy “co-shock” further speeding up the process. Similarly, I defined Hydro’s new corporate strategy as the “shock” promoting the initiation of “Fine Chemicals from Fish Waste.” At the same time, it is evident that the emergence of the fatty by-product acted as a shock triggering action in the first place: “What do we do with the “problematic” fat?”[436] To which extent is the finding of several possible “shocks” compatible with the assumption of a sequential order in which a gestation period, bringing forth an innovative idea, is followed by a “shock” triggering efforts to develop the idea? (Ref. Van de Ven et al., 1999). The answer depends

[436] This discussion implicitly points out that *all* the incidents I think of as potential ”shocks” are events reflecting perceived necessity, opportunity, and dissatisfaction. As such, my analysis supports the general assumption that these factors are the major preconditions stimulating the initiation of innovation efforts (Van de Ven et al., 1999). The ”Bearing Channel” project indicates that the prospect of a ”prolongation” of EXPOMAT through PROSMAT was an opportunity boosting people’s discussion of new project ideas. The ”Empirical Modeling” and Omacor™ projects indicate that necessity (the need to deal with fatty by-product) or dissatisfaction (Process data are not made further use of!), combined with the opportunity to do something favorable about the situation, were major triggers in the respective initiation periods. Finally, the ”Die Life” project is a striking example that necessity, the urge to deal with a problematic situation, stimulates people to act.

on the labeling of events. If I consider the prospect for the EXPOMAT program and the new corporate strategy as the "shocks", my data fits the MIRP framework. On the other hand, if I regard the die life problem and the emergence of the problematic fat as the respective "shocks", the linear assumption is no longer valid: The shocks boost the gestation periods and the emergence of innovative ideas, rather than act as forces stimulating efforts to develop innovative ideas already in existence. This is also the case with the initiation periods of "Modeling of Friction" and "Modeling of Properties". Here the shock in terms of the prospect for the PROSMAT program stimulated efforts to develop project ideas in the first place. Thus, with exception of the "Empirical modeling" project that seemingly follows the gestation period-shock-plan sequence very well, the other case projects indicate that the MIRP researchers' presentation of the initiation period represents an *ideal* linear model that does not account for the real complexity of the early periods of innovation processes. As such, the MIRP researchers' conceptualization of "shocks" as the demarcation between the gestation period and the following period stimulating concentrated efforts to initiate innovations, appears to be simplistic.

Third, no matter which incidents are labeled "shocks", the MIRP framework suggests that the initiation period results in an "innovative idea." What were the "innovative ideas" of the case projects like? The case projects point out that the "innovative ideas" may be defined as suggestions or "working hypotheses" that help in directing inquiry and examination (Darsø, 2001). First, the "innovative ideas" represented open-ended problems: The gap between pure storage and actual utilization of logged process data ("Empirical Modeling"); the gap between short and long die life ("Die Life"); the gap between variations in strength and "zero" variances ("Modeling of Properties"); the gap between no satisfactory models and proper models of flow in the bearing channel ("Modeling of Friction"); and finally, the gap between the mere presence of, and commercialization of a by-product (Omacor™ project). Second, the "innovative ideas" embodied at least one purpose: Better extrusion process management ("Empirical modeling"); development of the next generation of extrusion dies for AA7000 profiles ("Die Life"); tighter tolerances ("Modeling of Properties"); prediction of how process parameters affect the final properties of the product/reduction of variations in strength of extruded section by more than 50 percent ("Modeling of Friction"); and finally, commercial utilization of fine chemicals from fish waste/development of an omega-3 high-concentrate (Omacor™ project). Some purposes were broadly defined, others were quite specific. Still others reflected both vague and more specific purposes (e.g. "fine chemicals" versus "omega-3 fatty acids"). Third, the "innovative ideas" reflected strategies to obtain the purpose: Implementation of empirical models; modeling of friction; modeling of properties; and multiple approaches (FEM modeling, fracture mechanics, better procedures). In sum, the "innovative ideas" represented rather vague suggestions in terms of intertwined problems, purposes and strategies. Ergo, my data suggests that "the transformation of innovative ideas into concrete reality" (Van de Ven et al., 1999), presupposes further specification of the "innovative ideas", including problem definition and the generation of new ideas.

Fourth, perceiving the "innovative idea" as the product of the gestation period, I find that the gestation period of the case projects was indeed about idea generation. Yet, the MIRP researchers' emphasis on the "innovative idea" as "The Very Innovative Idea" ignores my finding that *several* ideas were created during the gestation periods of these case projects. For this reason, several ideas may be regarded candidates for the superior position as the "innovative idea". For instance, the "innovative" idea of using empirical modeling for extrusion process management was a *response* to the initial idea of utilizing empirical process data. It embodied the original idea while simultaneously containing a solution to how process data could actually be made use of. This also applies to the "innovative ideas" in the "Modeling of Friction" and "Modeling of Properties" projects. The idea of developing friction models represented an answer to the question of how the idea of modeling flow in the bearing channel could become a reality. Similarly, the "innovative idea" of modeling properties was a response to the idea of bringing variations in strength into focus. It is difficult to say whether the "innovative ideas" were more "innovative" than the original ideas from which they emerged. However, the point is not which was the very "innovative" idea: *The point is that the gestation period appears to be a dynamic process in which one idea, e.g. a response to observations, reflections, and initiatives, triggers subsequent ideas in a continuous pattern, forming a chain of ideas.* Each idea represents a single moment in an ongoing reflective conversation (Schön, 1983). Thus, the MIRP researchers' "innovative idea" is simply one idea cut out of a chain of ideas, most probably, the idea appearing in the plan preceding the initiation of an innovation project. Taking account of the suggestion that the "innovative idea" requires further specification, it also becomes evident that the "innovative idea" will trigger further ideas. It follows that the MIRP researchers' use of "plans" as the demarcation line between the "initiation" and "development" period should not be regarded as a clear boundary between idea "creation" and idea "development." In fact, my analysis of the gestation periods indicates that the processes usually treated as sequential phases of "idea generation" and "idea development", are continuously intertwined.

Fifth, the foregoing findings suggest that the MIRP framework provides a useful macro-perspective in terms of giving a broad overview of the respective initiation periods. At the same time, they show that the framework does not account for the real complexity of the early periods of innovation processes. As such, it is not suitable when it comes to the subtle process dynamics revealed in the case projects. Likewise, neither Argyris and Schön (1996) nor Nonaka and Takeuchi (1995) are particularly helpful here. In contrast, the writings on improvisation reflect a perspective that fits in with my findings. Therefore, I now take a new look at my findings in light of the framework of improvisation.

Jazz musicians play, tune after tune. It is an ongoing stream of music - melodic themes, harmonic chord progressions, solos, accents, cymbal crashes, and shifting dynamics. I enter the jazz club at some point during their concert, defining this moment as the ”beginning” of their performance. Similarly, I enter into Hydro, cutting moments from an ongoing flow of activities, labeling them the ”beginnings” of the case projects. No matter which moments I choose, the ”beginnings” guided Hydro employees in their inquiry from that specific point in time. The innovative idea of applying FEM modeling to extrusion technology, the customer request for stronger bumper beams, and the attempts to produce enzymes from fish waste, all mirrored the material people improvised from the "beginning" onwards. (Weick, 1998). Moreover, the project members' setting of the problem, the process in which they interactively named the things to which they would attend and framed the context in which they would attend to them (Schön, 1983), provided the *form* acting as the pretext for further work (Weick, 1998).[437] The form represented the minimal structures that allowed members of the project teams to play in a coordinated fashion. The idea of applying modeling techniques for extrusion technology, the decision to extrude bumper beams in AA7000 alloys, and the use of ensilage technology to produce enzymes from fish waste are ”Hydro equivalents” of the sequence of harmonic chords and the scheme of rhythm guiding improvisation on simple melodies. Furthermore, the project members' competence formed the basis for their capacity to keep inquiry moving. Similar to jazz improvisation which presupposes that musicians know the theories and rules governing musical progression, the Hydro activities required a variety of highly skilled professionals:

[437] As discussed in Chapter 5.6.3, jazz improvisation materializes around a simple melody whose form provide the pretext for real-time composing (Weick, 1998).

People with specialist competence on FEM modeling techniques, material technologists, chemists, press plant operators, etc. The team members' individual and collective efforts provided outcomes such as "promising" results regarding the application of FEM modeling techniques, "catastrophically" short die life, and a fatty by-product. Next, project members' response to these effects guided further inquiry. For instance, listening to the "FEM modeling for extrusion technology" - melody, two Hydro managers regularly met to discuss ideas inspired by the ongoing stream of research activities. Their recognition of the huge amounts of stored process data triggered a new idea: "Is it possible to use the data in a smart way?" In turn, the managers' knowledge of empirical modeling techniques acted as a cue allowing this idea to get louder and louder: "Is empirical modeling a possible strategy here?" The interrelated suggestions operated as new chords moving the music away from the original melody; "FEM modeling" chords were replaced with "empirical modeling" chords. The Hydro people played on, inviting other people into the exploratory process. The dialogue between one of the managers and a SINTEF researcher made the idea of empirical modeling rise to a new crescendo. The SINTEF researcher happened to know people working on empirical modeling techniques and kept inquiry moving by introducing the idea to people in the relevant SINTEF department. These people found the idea highly interesting. Their supportive response set the tone for several meetings in which Hydro people and SINTEF researchers exchanged ideas, elaborating on the "empirical modeling" theme. The involvement of specialists on empirical modeling provided the project band with retrospective access to a greater range of resources, i.e. improved *memory* that improved improvisation (Weick, 1998). Their entrance bears resemblance to the entry of string bass players in a band composed of "high pitch" instrumentalists who play with the idea of performing some new type of music, but who are not sure whether this is viable. The string bass players have performed similar music with other types of "high pitch" instrumentalists. They know that their special competence is widely applicable. And as the string bass and "high pitch" players play together - listening to each other's ideas, supporting and "comping" each other, introducing new phrases and chords - the idea of performing the new type of music rises to a mighty crescendo. Similarly, the reflective conversations between Hydro personnel and SINTEF researchers made the group arrive at the conclusion: Yes, empirical modeling is indeed a possibility! Thus, the idea of using empirical modeling techniques for extrusion process management emerged from a *dialogic interaction* between several people. The process was a guided activity based on retrospective sense making. People were in dialogue with each other and with their material; prior ideas fashioned subsequent ones as new voices contributed with new suggestions. People listened to each other's and their own comments and built on them. The gestation period was a flow of ongoing invention (Barrett, 1998). This analogy applies to the other case projects as well. Furthermore, the framework of improvisation points out that the so-called "innovative idea" (Van de Ven et al., 1999) is not The Very Innovative Idea. *The "innovative idea" is simply the idea that guides the further collective inquiry in the projects; it is the melody people improvise on from the formal project start-up*.

To facilitate the further analysis and discussion, I define the ideas appearing in the plans preceding the initiation of the case projects as the "innovative ideas". I now elaborate on how the "innovative ideas" unfolded over time from the development period on, paying particular attention to the proliferation process. As discussed in Chapter 5.6.2, the *development* period is the period in which concentrated efforts are undertaken to transform the innovative idea into a concrete reality (Ref. Van de Ven. et al., 1999). *Proliferation*, which is a common process characteristic of the development period, denotes the proliferation of the initial innovative idea into numerous ideas and activities when the development activities begin.

11.2.2 A Glimpse of the Development Period

The Omacor™ Project

The unfolding of the "innovative idea" of the Omacor™ project from the formal project start onwards is illustrated in Figure 11.2.7. The aim of the Omacor™ project (whose original title was "Fine Chemicals from Fish Waste") was to find methods for isolating commercial products, such as fatty acids and steroids from fish waste, and thereby create a profitable utilization of by-products from the fish industry. During the fall of 1984, Harald Breivik, the project manager, made a preliminary literature survey aimed at exploring areas of use, prices, market, etc. for some of the fine chemicals expected to be in the fatty fraction of the ensilaged fish waste.[438] The relevant groups of fine chemicals were unsaturated fatty acids (the polyunsaturated omega-3 fatty acid EPA and two others representing other groups of unsaturated fatty acids), steroids/cholesterol and tocopherol (vitamin E) (see Figure 11.2.7). Among these, the market for unsaturated fatty acids appeared to be the most promising. Yet, Breivik emphasized the importance of gaining as much detailed knowledge as possible on other components in fish waste before arriving at the decision on which of

[438] "Finkjemikalier fra fiskeavfall. Vurderinger ved start av prosjekt i Analytisk avdeling". 1984-11-22

the fine chemicals that should be given priority. The proposed plan was initial analyses followed by preparative separation and isolation of the components that turned out to be most interesting.

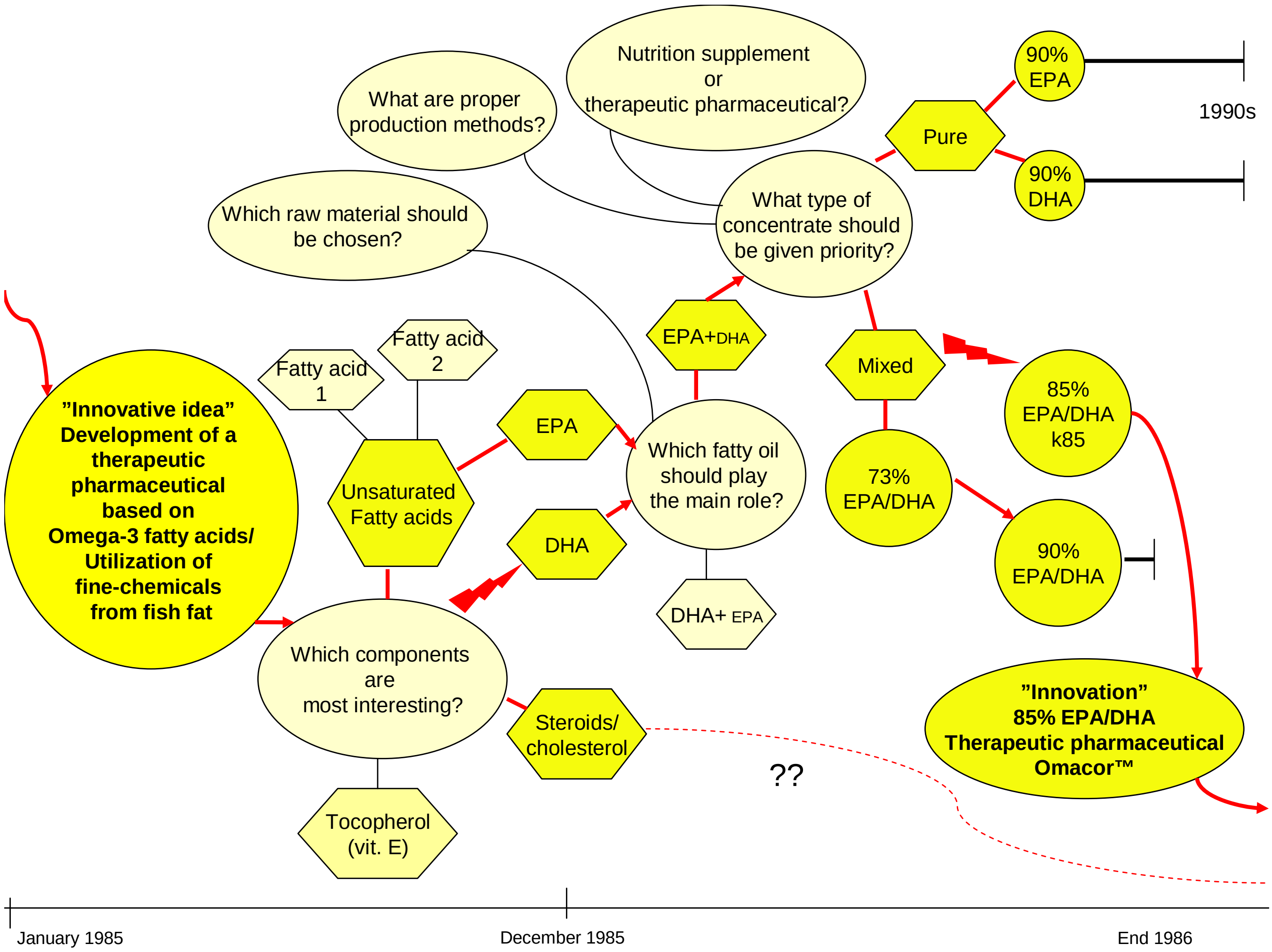

Figure 11.2.7 The Unfolding of the "Innovative Idea" in the Omacor™ Project.

According to the plan, project participants were to decide on what fine-chemicals to give priority to in the end of 1985. Thus, although the vision of an omega-3 high-concentrate was a driving force, "what we were to produce was relatively open-ended", as a project member remarked.

During 1985 the initial focus on fine chemicals was narrowed down to the omega-3 fatty acids EPA and DHA and cholesterol.[439] Closer investigations revealed that the other fine-chemicals would not be commercially viable. The attention to the omega-3 fatty acid *DHA*

[439] I have no information about the further work on steroids/cholesterol, as indicated by the dotted line and questions marks in Figure 11.2.7

is noteworthy. As discussed earlier, three different unsaturated fatty acids appeared to be of initial interest: EPA and two others representing other groups of unsaturated fatty acids (see Figure 11.2.7). However, through their analysis of the fish fat, Breivik and his colleagues surprisingly discovered that the fish fat contained large amounts of DHA, another omega-3 fatty acid that the researchers thought were not very important when they started (illustrated by the bolt of lightning in Figure 11.2.7). In fact, the content of DHA in North Atlantic fish appeared to be higher than the concentration of EPA. This observation triggered a discussion on which fatty acid were to play the main role, an issue that, in turn, was closely linked to the question of which raw material from fish to use (see Figure 11.2.7). DHA would imply continued use of North Atlantic fish, whereas EPA would imply the need for "foreign" raw material.

The content of omega-3 fatty acids depends on the kind of fish used, seasonal variations, which parts of the fish that is used, and the conditions for storage of fish waste.[440] As just indicated, the DHA/EPA discussion was basically focused on giving priority to DHA, implying the use of North Atlantic fish oil, in particular fish oil based on fish entrails because it provided higher concentrations of DHA and EPA than whole fish, *or* deciding to let EPA play the main part, thereby taking "foreign" raw material into use. Thus far, EPA had received most attention in the international research context. But, as Breivik argued at the end of 1985:

> *…Despite the fact that studies, almost without exceptions, have been carried out with EPA/DHA concentrates, EPA has so far alone been given the credit for the beneficial effects observed. Now corresponding beneficial effects of DHA is far more often explicitly mentioned…*[441]

From a commercial point of view, Breivik assumed that their DHA/EPA- concentrate, which had a concentration of DHA that was considerable higher than what was found in commercial concentrates at that time, would imply a positive price effect.[442] For this reason, fish waste with a high content of entrails was a favorable raw material for the production of an omega-3 high-concentrate, meaning it would be beneficial for Hydro to continue with fish waste and attach greater significance to DHA.[443] Taking clinical effects into account, Breivik also emphasized the importance of acquiring documentation on

[440]"Finkjemikalier fra fiskeavfall. Status ved utgangen av 1985." 1985-12-19
[441]"Finkjemikalier fra fiskeavfall. Status ved utgangen av 1985, p.8 (My translation into English)." 1985-12-19
[442]"Finkjemikalier fra fiskeavfall. Status ved utgangen av 1985." 1985-12-19
[443] "Produksjon av omega-3 konsentrater, EPA og DHA. Status august 1986." 1986-09-02

optimal proportions of EPA/DHA. Such documentation should form the basis for making a proper decision on raw material.[444] While the project manager argued in favor of paying greater attention to DHA, other project members held EPA to be the most important fatty acid due to its current international esteem. During 1986 the case went in favor of EPA and the latter point of view.[445]

The decision of giving priority to EPA, in turn, brought the question of what type of concentrate to develop, a *mixed* EPA/DHA concentrate or pure EPA/DHA (see Figure 11.2.7). The discussion reflected two interrelated questions: *Should Hydro go for a nutrition supplement or a therapeutic pharmaceutical*? (Including the question: *What level of purity (concentration) was needed to meet the requirements for therapeutic pharmaceuticals?*) and *What are proper production methods for omega-3 high-concentrates*?[446] By means of one method, the researchers managed to produce a 73 percent EPA/DHA concentrate (the "raw concentrate"). By means of another method, they managed to isolate some grams of pure 90 percent EPA and 90 percent DHA from the raw concentrate. In the Status report of December 1985 Breivik stated that the mixed concentrate could be sold as a nutrition supplement whose quality was at least equivalent to the ones that were already present in the Japanese and American markets[447]. On the other hand, he assumed that the pure fatty acids had sufficient purity to become a therapeutic pharmaceutical product. Breivik and his colleagues knew that some Japanese researchers were about to apply for product approval for a 90 percent EPA product. For this reason, the researchers assumed that a concentration of at least 90 percent held "pharmaceutical quality". Thus, the discussion on mixed versus pure concentrates was accompanied by the question of nutrition supplement versus therapeutic pharmaceutical. Bernt Børretzen, who proposed the idea of making an omega-3 "heart medicine", summarized the discussion as follows:

> *…There were some discussions back and forth on whether we were to go for a nutrition supplement or a therapeutic pharmaceutical. We thought all the time that we should go for a medicine, that is, k85 as a therapeutic pharmaceutical…*[448]

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[444]"Produksjon av omega-3 konsentrater, EPA og DHA. Status august 1986." 1986-09-02

[445]Still, project members emphasize that that the choice of EPA was not the *only* factor influencing the decision to leave fish waste as a raw material. Project members soon realized that the amount of ensilaged fat produced in Tromsø was not sufficient for their activity, and they decided to buy samples of fish from different companies in the North. In addition, the EPA-decision was in line with the process technology used by Martens, the first fish oil plant to be acquired. Here, Norwegian fish oil could not be used because of its large content of mono-saturated fatty acids.

[446]For reasons of space, I postpone the discussion of the relationship between the issue of mixed versus pure EPA/DHA and efforts directed at developing proper production methods to Chapter 12.

[447]"Finkjemikalier fra fiskeavfall. Status ved utgangen av 1985." 1985-12-19

[448] Børretzen in "Forskningsposten 7/93"

At the end of 1986, Hydro researchers were able to produce some kilograms of a 90 percent EPA/DHA concentrate, that is, an additional omega-3 candidate of pharmaceutical quality. They obtained the high-concentrate by extracting DHA and EPA from the 73 percent raw concentrate.[449] Having developed one mixed and two pure 90 percent omega-3 concentrates, the researchers agreed to base the final decision regarding mixed/pure products on market surveys. In this connection, Breivik had previously pointed out that the production of pure concentrates might prove to be expensive compared to the production of a mixed concentrate that could be produced in large quantities at relatively low cost[450]. At the same time, Hydro's acquisitions of two fish oil companies in 1987 (Martens) and 1988 (Jahres fabrikker) proved to have a decisive influence on the further path of the project (indicated by the bolt of lightning in Figure 11.2.7).

As described earlier, Hydro researchers managed to produce some kilograms of a mixed 90 percent EPA/DHA concentrate. Still, they were yet not able to produce the concentrate in a full production scale. However, by means of acquired production technology, Hydro researchers managed to produce an 85 percent EPA/DHA concentrate in large quantities. In the words of Breivik, "*Then suddenly, through Martens' molecular distillation we were able to make an 85 percent concentrate in large quantities. Now it was laughter and joy*!" The initial goal of a 90 percent concentrate was then redefined to an 85 percent concentrate. The efforts directed at developing the 85 percent concentrate (*k85*), the product that later was named Omacor™, was given high priority from 1987 (see Figure 11.2.7). Breivik reported: "*Most probably, this is the product we will attend greatest attention to in the future*."[451] Still, Hydro kept up the activity on pure products. In particular, the attention to pure products was seen as important regarding investigations of the individual efficacy of EPA and DHA respectively. This activity was given increased priority towards the end of the 1980s, resulting in several patents. During the 1990s however, it was terminated, probably for economical reasons" as one of the project members expressed himself.[452]

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449 The process was carried out at a French pilot plant (Ref. "Produksjon av ω3-konsentrater, EPA og DHA. Status august 1986". 1986-09-02.

450 "Finkjemikalier fra fiskeavfall. EPA, DHA og kolesterol i torskeensilasje." 1985-06-21

451 "Omega3-konsentrater fra fiskeoljer. Status februar 1987." 1987-02-23

452 Looking back at the discussion on mixed or pure Omega-3 medical products, Breivik made the following reflections:

> *…At that point in time we said that both* [EPA and DHA*] are omega 3-fatty acids. Today we know that the fatty acids have different properties. Thus, if we had started the project today I assume that we would have made separate concentrates of each acid and developed documentation on the individual efficacy of the respective fatty acids –maybe. In any case, I imagine that the authorities of today* [i.e. in 2001] *would prefer pure products, not a mixture. That's how I think, but I am not necessarily right…*

Thus, the outline of the initiation period of the Omacor™ project shows that the initial idea of commercial utilization of fine chemicals from fish-waste narrowed down to the development of omega-3 concentrates based on fish oil. At the same time, the idea of an omega-3 high-concentrate soon proliferated into several ideas (mixed/pure concentrates) that proceeded in parallel paths of development, of which *k85* finally received the greatest attention.

The "Die Life" Project

The unfolding of the "innovative idea" of the "Die Life" project from the formal project start onwards is illustrated in Figure 11.2.8. The "innovative idea" of the "Die Life" project reflected a multiple strategy to obtain the next generation of extrusion dies for AA7000 alloys. The overall strategy was an optimization of existing die design. According to the working plan, 3D FEM stress analysis, modeling of load[453],and die material and fracture mechanics[454] should be given priority (see Figure 11.2.8). Still, Sigurd Rystad, the subproject manager, argued that the initial working plan was not sufficient; further preparations were needed to ensure that the most relevant and proper work methods and approaches to the problem were chosen. In particular, he spoke in favor of making a thorough evaluation of methods and results achieved in the EXPOMAT program. He also emphasized the importance of discussing the proposed project plans with as many relevant research groups and competent persons as possible. As a consequence, the "Die Life" project started with a four-month pre-study.

During the pre-project Rystad arranged a number of meetings with people from NTNU, SINTEF, Hydro Aluminium Extrusion, the steel manufacturer, and the research centers at Karmøy and Raufoss. Project participants studied relevant literature to learn about experiences and results obtained by others. Discussions revealed that the EXPOMAT project had resulted in lots of information about die design. However, the great amount of data was stored in separate reports that were not well systematized and difficult to access. Accordingly, collection and systematization of this knowledge were given priority during the pre-project.[455]

[453] Modeling of load concerned metal flow simulations providing important input data for the stress computations.
[454] Emphasis on die material and fracture mechanics included crack investigations and work on steel quality and heat treatment.
[455] Minutes from Meeting 1996-03-27

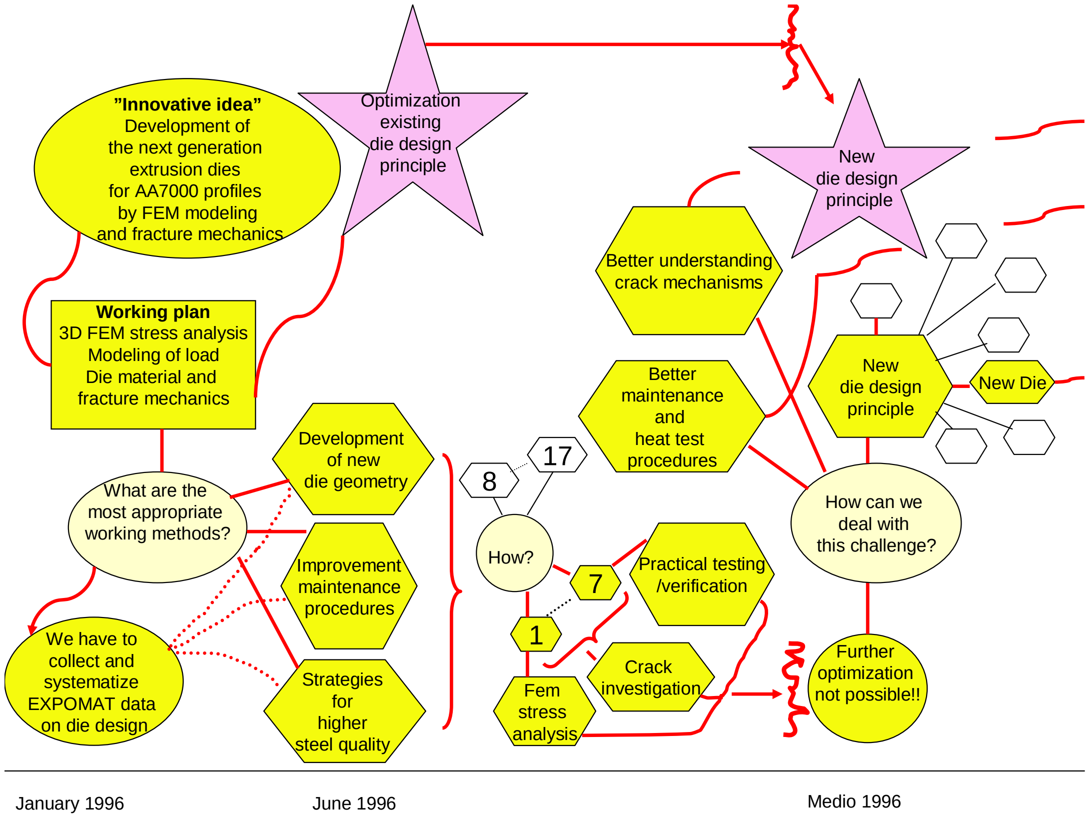


Figure 11.2.8 The Unfolding of the “Innovative Idea” in the “Die Life” Project

The pre-study activities resulted in several recommendations and project suggestions presented in the pre-study report of June 5, 1996.[456] Emphasizing the importance of taking advantage of and implementing new technology developed in other projects, Rystad reported that the project goal could be reached through development of new die geometry, improvement of maintenance procedures, and strategies enabling better steel quality.The development of new die geometry and changes in maintenance procedures for the dies was important to obtain the lowest possible stress levels where the crack started. In this connection, Rystad regarded the ability to take advantage of and implement new technology developed in other projects as ”extremely important”. The attention to steel quality concerned actions to make sure that the steel quality was as good as possible and stable over time. In particular, Rystad emphasized the importance of obtaining the knowledge necessary to choose the best steel parameters such as hardness and surface quality. He presented seventeen project possibilities representing a further specification and elaboration of how the actions could be carried out. Among these, Rystad identified seven that could

[456] PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Subproject 1 Strength Analysis and Fracture Mechanics. Pre-Study Report. 1996-06-05

act as start-up activities. These activities covered FEM stress analysis, crack investigations, and practical testing to verify the FEM computations (see lower part of Figure 11.2.8).

The main project started in the summer of 1996. In addition to the SINTEF researchers, Rystad engaged local staff members in the project. He established an internal project team. Within a short time, initial stress analysis and practical tests revealed that the die design at that time had reached its limit with respect to die life; further optimization was not possible (see Figure 11.2.8). Accordingly, a new die design was needed to avoid the cracking problem. This conclusion is recognized as a critical incident of the project, forcing rethinking. In the words of a project member, "*We had to forget everything we had learned so far and try to hit upon something new*". Facing this great challenge, Rystad decided to arrange a large brainstorming meeting to generate ideas for a new die concept. Along with the project members, he invited several other experts, among others, Automotive staff members working on other forming processes. The brainstorming meeting was held in October 1996, emphasizing the challenge of doubling die life.[457] The participants concluded that a radical increase of die lifetime required a thorough understanding of crack mechanisms, i.e. knowledge about how and why cracks appear and destroy dies. They also stressed the importance of running the extrusion process in such a way that initiation and propagation of cracks were delayed, for instance through proper maintenance and heat management procedures. In addition, a number of principally different die designs were proposed. Initial evaluations showed that several ideas offered promising results, and further testing revealed that the so-called New Die concept was the most appropriate regarding reduction of stress in critical areas ("hot spot stress").

In other words, from 1997 on, the "innovative idea" of the "Die Life" project reflected the following multiple strategies: Better understanding of crack mechanisms, better maintenance and heat test procedures, and further development of the New Die design principle. From one point of view, the "innovative idea" of the "Die Life" project in 1997 was not very different from the one found in the project proposal. From another point of view, the 1997 version mirrors the change in overall strategy from optimization of existing die design to development of a "radically" new one.

[457] PROSMAT New Modelling Techniques for the Future Extrusion Technology. Subproject 1: Strength Analysis and fracture mechanics. Minutes of Meeting (Meeting held 1996-10-21) 1996-12-03.

The "Bearing Channel" Project

The unfolding of the "innovative ideas" of "Modeling of Properties" and "Modeling of Friction" from the formal project start onwards is illustrated in Figure 11.2.9. Similar to the other PROSMAT Extrusion projects, "Modeling of Properties" and "Modeling of Friction" started with a pre-study to clarify industrial needs, objectives and approaches to the problems. The pre-study for "Modeling of Friction" included discussions on idealized test methods for friction and evaluation of different methods for treating friction in the bearing channel. Based on meetings with, among others, professors working on molecular dynamics and friction at the University of Oslo, subproject manager Trond Aukrust and his colleagues decided to choose a friction model that was well established for metal forming (Coloumb friction) (see Figure 11.2.9).

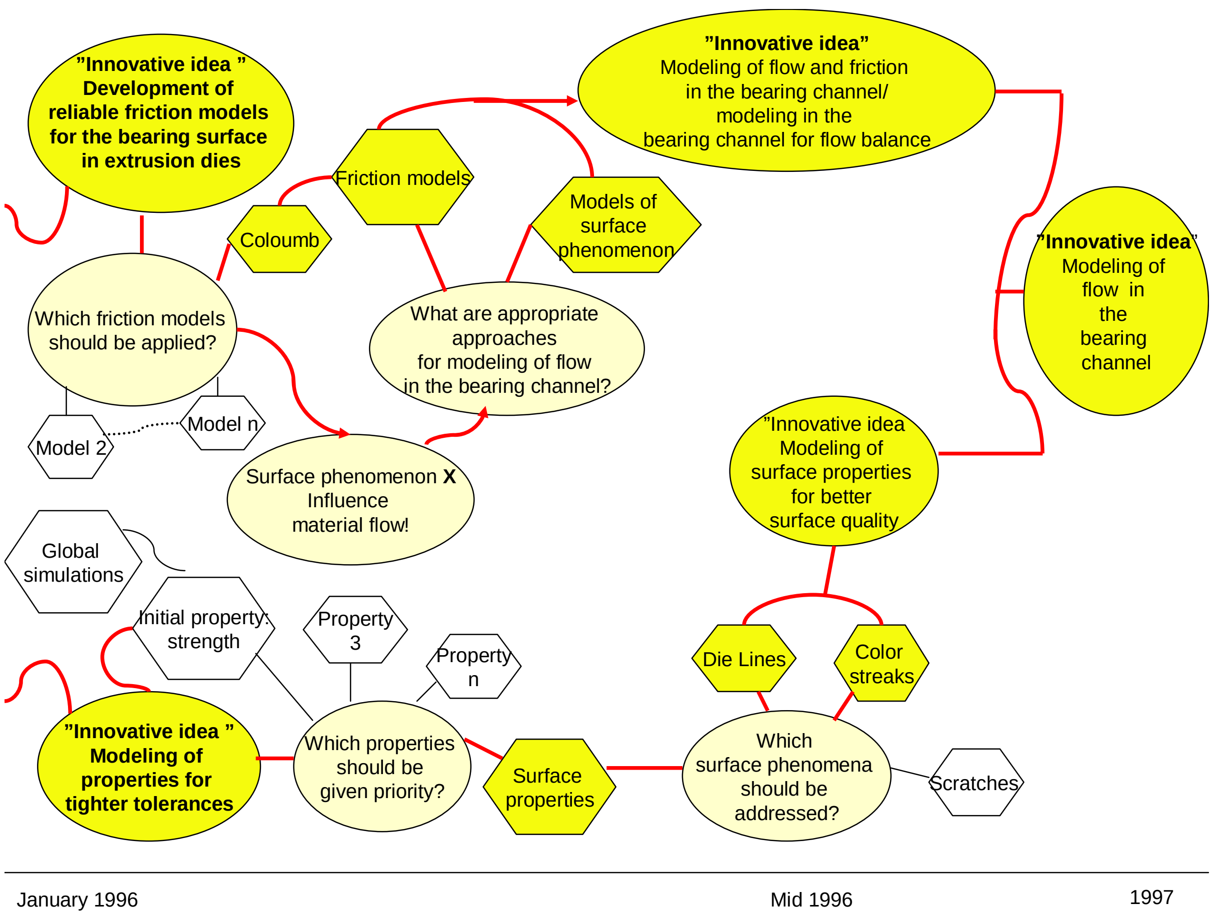


Figure 11.2.9 The Unfolding of the "Innovative Ideas" for "Modeling of Friction" and "Modeling of Properties".

Furthermore, discussions on material flow in the bearing channel brought a particular surface phenomenon into focus. Points were made that the material flow is influenced both by friction and material behavior resulting in a specific zone close to the bearing surface. Accordingly, considerations of appropriate approaches for modeling of flow in the bearing channel resulted in the decision to emphasize not friction modeling only, but the development of a model accounting for this surface phenomenon as well. In this way, the pre-study resulted in an expansion of the original scope. Aukrust suggested that the project title could be changed to “Flow and Friction in the Bearing Channel” or “Modeling in the Bearing Channel for Flow Balance”.

The industrial target of “Modeling of Properties” was to obtain smaller variances in strength in extruded sections. However, the client representatives in the steering committee emphasized that the project members were free to consider other properties for extruded sections than the mechanical ones. As such, evaluation of critical properties became a major issue in the pre-project (see Figure 11.2.9). Aukrust and his colleagues spent time traveling around, learning about essential problems within Hydro Extrusion. They also studied literature and had discussions with people at Hydro R&D centers, universities, and research institutes. The process of defining relevant problems soon brought *surface properties* into focus. This was because surface appearance was of major importance for the building sector, HAEX’s largest market. Visible defects could lead to costly complaints and new deliveries. The attention to surface quality was also influenced by ongoing Hydro projects dealing with surface phenomena.

In turn, this brought the question of which surface phenomena to address into focus. The most common surface defects were *scratches*, *die lines*, and *color streaks*.[458] The mechanisms behind scratches were quite well known, and project members assumed that the appearance of scratches could be reduced through better housekeeping. In contrast, the mechanisms behind the other surface defects were not well understood. Furthermore, publications highlighting surface defects were scarce at that time. As a consequence, one had no exact knowledge of how to correct dies or to make appropriate changes to reduce the defects. Die designers and die correctors at that time made use of various strategies to modify the bearing channel in order to correct improper flow imbalance and improve surface quality.[459] Even though the effects of the various strategies were known, they were not yet well understood. Besides, one did not how the different strategies compared to each other. Therefore, Aukrust recommended that the project should aim at a deeper understanding of the mechanisms behind die lines and color streaks and the development of

[458] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Pre-Study Report May, 1996.
[459] PROSMAT New Modeling Techniques for the Future Extrusion Technology. Project Report 1999

models for these phenomena. In turn, this understanding could provide knowledge of how to avoid these surface defects.

The project title was changed from “Modeling of Properties” to “Modeling of Surface Properties”, highlighting the change from mechanical properties/variations in strength to surface quality. The choice of surface properties created a close link to the friction/flow-modeling project. Modeling of friction was needed for the development of models that were able to predict surface appearance. Because of the close connection between the “friction” and “surface” projects, the projects were merged into one, larger subproject in January 1997. The project title became “Modeling of Flow in the Bearing Channel.” Thus, the original “innovative ideas” were modified and merged into the broader idea of modeling flow in the bearing channel.

The “Empirical Modeling” Project

The unfolding of the “innovative idea” of “Empirical Modeling” from the formal project start onwards is illustrated in Figure 11.2.10 below. The project started with a six-month pre-project aimed at finding proper ideas for practical application of empirical modeling techniques in Hydro Aluminium Extrusion. This was because the initial approach to the problem was open-ended, requiring a further evaluation of possibilities for systematic use of the data. One of the project members said:

> *…It really started with a creative phase aiming at finding proper ideas for practical applications… We stated that we wanted to make use of data. However, data could be made use of to work on the process, on dies. We could possibly use some downstream the process. We were not quite sure about what actually should be the case, then. So, at the time of start-up, we agreed to spend about half a year aiming at making a list covering five to ten possible areas of applications within empirical modeling. Then, afterwards we would make assessments on which areas to give priority to...*

The objective of the pre-study was to investigate potential application areas for empirical modeling techniques within Hydro Extrusion and to provide a basis and recommendations for the establishment of a 4.5-year research project. All elements in the production chain were to be considered and increased productivity, reduced risk, and improved quality control, were seen as possible benefits.[460]

[460] SINTEF REPORT No STF 72 F 96 618 1995-12-13 (restricted). New Modelling Techniques for the Future Extrusion Technology. Empirical Modelling. Prestudy report

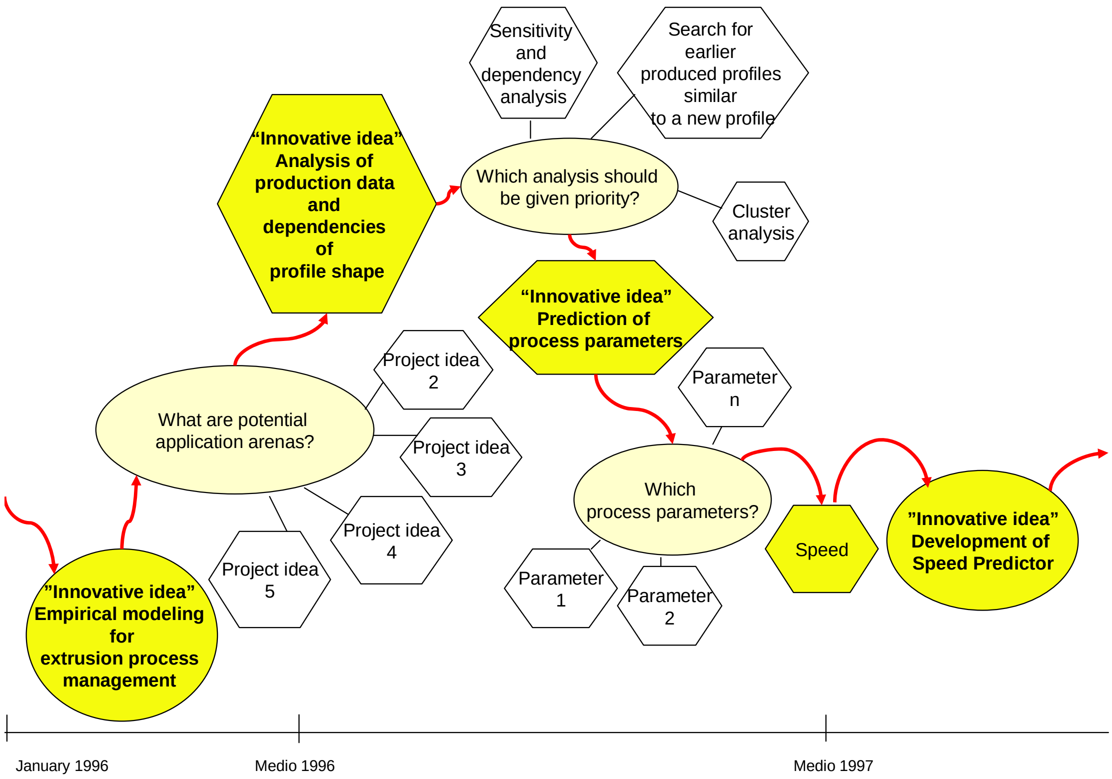


Figure 11.2.10 The Unfolding of the "Innovative Idea" in the "Empirical Modeling" Project

During the pre-study, Tom Kavli, the subproject manager, spent considerable time traveling, visiting several extrusion plants, tool manufacturers, software suppliers, and research groups in Norway and abroad. He collaborated closely with department colleagues and the Hydro manager who was the HAEX client representative in the steering committee. Based on the impressions from the visits and the discussions, Kavli prepared a pre-study report including a presentation of five major project ideas, reflections on where research should be focused to gain improvements, and an evaluation and recommendation of project ideas.[461] The idea named "Analysis of Production Data and Dependencies on Profile Shape" was regarded as the most promising, and Kavli proposed the start-up of a main project based on this idea. The pre-project report was presented to the steering committee in the summer of 1996, and the proposal of "Analysis of Production Data and Dependencies on Profile Shape" was accepted. The four alternative ideas were no longer given attention to.

[461] SINTEF REPORT No STF 72 F 96 618 1995-12-13 (restricted) New Modeling Techniques for the Future Extrusion Technology Empirical Modeling. Pre-Study Report.

Thus, about six month after the start-up, the "innovative idea" had been given a more specific formulation. Nevertheless, the idea named "Analysis of Production Data and Dependencies on Profile Shape" was not ready for implementation. The choice of this idea brought the following question into focus: Which analysis should be given priority? (see Figure 11.2.10). In the pre-project report Kavli presented four types of analyses that could be carried out on the relevant data: *Sensitivity* and *dependency analysis,* aiming to find which and how different profile and process parameters influence productivity, quality, need for test runs, costs of tool development, etc.; *prediction*, e.g. estimating the above kinds of variables for a new profile based on its shape; *cluster analysis* suitable for finding out if there were certain characteristics common for all high cost or high risk profiles; and finally, *search for earlier produced profiles which were similar to the new profile*. Kavli argued that software tools for the various kinds of data analysis and data modeling could be used for a large range of applications. In the pre-study he presented a list of sixteen potential applications covering users at several steps in the section production chain. The applications reflected the impression regarding potential for cost savings and productivity improvements from the previous visits to extrusion plants and tool manufacturers.

Kavli continued discussing possible applications with the HAEX client representative, people at extrusion plants, Hydro researchers, and SINTEF colleagues. The attention gradually narrowed into *prediction* of process parameters, which in turn led to the question of *which* process parameters? (see Figure 11.2.10). Within the summer of 1997, *prediction of press speed* for new sections emerged as the main theme. Speed prediction was seen as essential for dealing with the following production challenge: One press line at an extrusion plant may produce several thousand geometrically different sections every year.[462] Up to 1000 of these may be new sections not previously produced, implying that "*each day means new sections, new products and the need for estimation of productivity and other parameters*", as a project member said, adding: "*New dies have to be made and the press speed has to be estimated. This is about productivity. A new die means that you don't know how fast you may run*!" Accordingly, the development of a speed prediction tool seemed to be a sound idea. The concept was met with great interest in HAEX and among participants of PROSMAT Extrusion.

Thus, during the period from formal start-up to the summer of 1997 the "innovative idea" of implementing empirical models techniques in extrusion process management

[462] In 2003, Hydro had 100 press lines

gradually transformed into the idea of developing a speed predictor, as indicated by the red line in Figure 11.2.10. In turn, this idea formed the basis for further inquiry.

Further Analysis and Discussion

In sum, the outline of the development periods of the case projects show that the "innovative ideas" unfolded in a dynamic process that bears resemblance to the non-linear divergent-convergent system dynamics pointed out by Van de Ven et al. (1999). However, where the MIRP researchers note that the divergent-convergent activities are triggered by enabling or constraining conditions, my data suggests that *the cycles are primarily an inherent characteristic to the inquiry itself*. The case projects show that the project members' inquiry into the "innovative idea" at the beginning of the development period revealed the need for exploring Which/How/What-questions (e.g. What are potential application areas?/What are the most appropriate working methods?/Which components are most interesting?) This investigation aimed at developing new ideas in terms of solutions to the questions (divergent phase, see Figure 11.2.11).

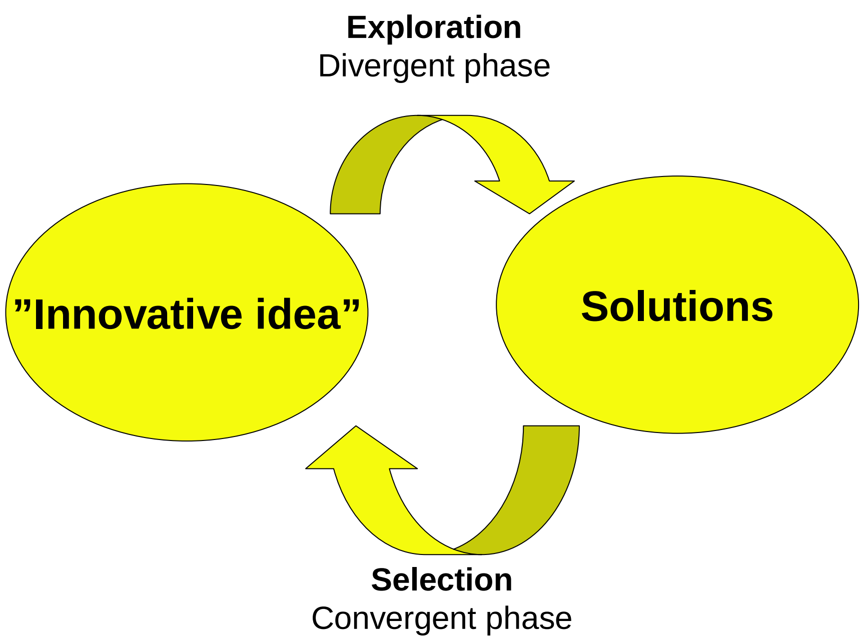


Figure 11.2.11 The Divergent-Convergent Dynamics through Which "Innovative Ideas" Unfold.

The solutions were then subject to evaluation and selection (convergent phase), triggering a new search for solutions to the chosen "innovative" ideas, and so on in an ongoing flow of inquiry.

Moreover, the alternation between "innovative ideas" and "solutions" (Ref. Figure 11.2.11) clearly shows that the inquiry is a collective *improvisatory* process driven by the participants' improvisation on the "innovative idea". Figures 11.2.7 through 11.2.10 offer a glimpse of this process, where the apparent "final" innovative ideas should be regarded as the ideas that guided inquiry from that point in time. I now analyze the development periods of the case projects by means of the improvisation perspective.

At the point in time defined as the start of the development period, members of all the case projects based their further inquiry on the "innovative idea," including proposed plans for progress and scheduled steps for research activities. A striking finding across all case projects is the emphasis on initial problem definition or *problem setting* (Schön, 1983). All the projects started with a period dedicated to thorough exploration and improvisation of the "innovative idea" in terms of investigatory What/Which questions. Led by the "innovation idea" and the "What/Which?"-theme, project members were supposed to develop and play with as many ideas as possible. In turn, evaluation and selection of the ideas were supposed to guide further inquiry. The project members' naming and framing of the "innovative ideas" provided the moderate constraints needed for guiding people to a common place while simultaneously allowing them the freedom to approach the problems in ways that made the most of their competence.[463] The pre-project phases of the PROSMAT Extrusion projects (as well as the first year of the Omacor™ project) provided several ideas and suggestions that were subject to evaluation and selection. The project bands kept playing the underlying "innovative idea"- melody, but each selection process took the music in a new direction, proposing further inquiry on new What/How/Which-themes. In turn, collective inquiry into these new themes provided new ideas followed by new selection, and so on in an ongoing flow of inquiry. As such, the idea development processes involved recurrent *framing* and *reframing* (Bolman and Deal, 1987) of the "innovative idea."

Equally important, the case projects show that the problem setting was primarily a *collective* inquiry. Ideas and suggestions emerged through reflective conversations between several people. For instance, the PROSMAT Extrusion projects show that project members emphasized the importance of involving as many relevant people in their pre-project inquiry as possible. Listening to suppliers, manufacturers, and people at extrusion plants,

[463] In Weick's (1998), the moderate constraints resulting from the problem setting process provided the form acting as the pretext for further work. Moreover, it is evident that the moderate constraints acted as the minimum critical specifications providing responsible autonomy (Morgan, 1997).

project members learned about relevant needs, interests, and problems. The "comping" project members (Barrett, 1998) built on this information, proposing ideas that could meet the needs and interests of the relevant actors. In addition, project members invited research groups to play with them. This approach enabled a great diversity of specialists representing a wide range of competence. In musical terms, the mixture of voices and instruments made it possible to play the "What/Which" theme with a wide variety of tone colors, ranges, dynamics, and expressions; it expanded the project band's field of action and interaction.

Furthermore, the project members continued their collective inquiry in the same fashion from the main project period onwards. They generated and selected ideas in a close social interplay. The "Die Life" project provides a striking example of the ongoing attention to collaborative efforts and a collective reflective practice (Schön, 1983). When the joint efforts of diverse specialists revealed that further optimization of the die design was not possible, the project manager invited a great number of specialists to the stage in order to keep the inquiry moving. Neither he nor other project members knew what a new die design would be like. Nor could they be sure that a new appropriate design could be developed at all. Yet, the project manager managed to cope with the unexpected situation. He acted as a *bricoleur* (Barrett, 1998), assuming that a solution could be worked out from the interplay between different specialists. Equally important, when asking people to play in the "Brainstorming" band, he did not restrict his attention to the most obvious players only. The project manager emphasized the importance of inviting people working outside the extrusion division. As such, he acted like a jazz band leader inviting instrumentalists from the traditions of classical music or folk music on stage. He assumed that they would contribute with unique voices and provocative competence (Barrett, 1998), helping the band challenge habits and conventional practices.

The "brainstorming" band members played well together, investigating several questions. The collective reflection provided several ideas that formed the basis for further experimentation. The band members still improvised on the "Development of the next generation extrusion dies for AA7000 alloys" -melody, but they had substituted the original "optimization" chord progressions with "new design" chords. The project manager and his colleagues were good improvisers, developing *action*. They acted their way into the future, listening to the situation's backtalk (short die life) and embracing the failed strategy as a source of learning. They had an accepting attitude, appreciating the contributions of others, not least the offers given by “strangers” and they believed in the power of collective reflection and dialogue.

Moreover, the case projects also show that project members were in continuous *dialogue with their material* (e.g. laboratory analyses, literature, industrial needs, problems, and interests) (Weick, 1998). The project members were in a reflective conversation (Schön, 1983) with the unique and new situation. They were open to unexpected cues, welcoming them in the same way jazz musicians respond to the introduction of new chords or phrases. For instance, researchers in the Omacor™ project surprisingly discovered that the fish fat contained large amounts of the fatty acid DHA. Members of the “Die Life” project found that a great amount of previous project results were not well systematized and difficult to access, and later realized that their initial optimization strategy did not work. Similarly, the discussions on modeling of friction revealed that a particular surface phenomenon influenced material flow in the bearing channel. Listening to the situation’s back-talk (Schön, 1983), the respective project members responded by including DHA in the further inquiry, by giving priority to collection and systematization of relevant information and the development of a new design, and by recognizing that the surface phenomenon had to be taken into account. In other words, the project members improvised; they reworked pre-composed material and designs in relation to unanticipated ideas conceived, shaped and transformed under the special conditions of performance (Barrett, 1998[464]). Thus, it follows that people in the case projects relied on retrospective sense-making as form (Barrett, 1998): The “innovative idea”, the “What/How/Which”- questions, the competence, thoughts, and opinions of people invited “on stage,” and existing information in terms of explicit information stored in data bases and files, represented the material people improvised on. The project members were not necessarily able to look ahead at what they were going to play, but they looked behind at what they and others had performed earlier. As such, each new step in the inquiry could be shaped in relation to what had gone before. It is also evident that the project managers emphasized the concept of *bricolage*, the art of making use of whatever is at hand (Barrett, 1998). The project members were encouraged to look over the material available at that point in time.

Finally, the case projects point out that project members’ inquiry gradually transformed the “innovative idea” into new ideas more or less in resemblance of the original one. The ideas presented as the “final” ideas of “Empirical modeling”, the “Die Life” project,

[464] Barrett (1998) cites Berliner (1994).

"Modeling of friction" (later the "Bearing Channel" project), and the Omacor™ project all embodied the original "innovative idea," defining the point of departure for the projects: The idea of making a speed predictor represented a practical application of empirical modeling techniques for extrusion process management; the suggestions concerning crack mechanisms and procedures combined with the idea of the New Die manifested the idea of developing the next generation of extrusion dies for AA7000 alloys; the suggestion to model flow in the bearing channel mirrored the idea of modeling friction; and the 85 percent EPA/DHA concentrate (which became the patented approved therapeutic pharmaceutical Omacor™) exemplified the idea of commercial utilization of the fish fat/the development of an omega-3 "heart medicine". At the same time, the "final" ideas of the "Die Life" and Omacor™ projects reflected that part of the original idea had been left out: The optimization strategy was substituted with a strategy aimed at developing a new die design, and the idea of commercial utilization of the fish fat was replaced with the idea of using commercial fish oil as raw material. These changes emerged from the ongoing inquiry and project members' response to unexpected setbacks and opportunities. However, because of the project members' mutual orientation around the basic root movement of the "innovative idea" chord patterns, basic chords could be substituted (Barrett, 1998). In contrast to the other case projects, "Modeling of Properties" (later the "Bearing Channel" project) shows that the "final" idea bore little resemblance to the original idea. The project members were allowed to redefine the initial restrictions "modeling", "property=strength", and "tighter tolerances" into "modeling of properties" in general. This allowed for an expansion of their field of action. In this way, the "Modeling of Properties" suggests that the smaller the "minimum structures," the larger the possibility for the emergence of "unexpected" ideas that are closer to a new composition than the original idea.

11.2.3 Final Summary Discussion

In the above analysis I have shed light on the initiation periods of the case projects as well as parts of the development periods to study how "innovative" ideas emerge and unfold over time. The analysis exhibits interesting findings. First, my data calls attention to that the very conceptualization of an "innovative idea" is problematic. Similar to traditional linear models of innovation, the MIRP model points out that the initial phase provides an "innovative idea" that forms the basis for innovation efforts. In a way, my case projects support this notion, not least because I find it appropriate to define the ideas appearing in the initial project plans as the "innovative ideas". Yet, they demonstrate that the gestation period is not about the creation of one clearly identifiable "innovative" idea. Rather, the gestation period is about the generation of *several* ideas, of which all serve as candidates for the superior position as the "innovative idea". In fact, my data suggests that the gestation period is a dynamic process in which *one* idea, e.g. a response to observations, reflections, and initiatives, triggers subsequent ideas in a continuous pattern, forming a *chain of ideas*. Each idea represents a single moment in an ongoing reflective conversation (Schön, 1983), and it is difficult to identify the truly "innovative" one; the subject is matter to interpretative flexibility (Pinch and Bijker, 1987). For this reason, the MIRP researchers' presentation of the so-called "innovative idea" as "The very Innovative Idea" is misleading. The "innovative idea" is simply one idea cut out of a chain of ideas, underscoring my argument that facts and artifacts are social constructions (e.g. Berger and Luckmann (1966); Pinch and Bijker, 1987).[465]

Second, no matter which idea is labeled the "innovative idea", the case projects show that the innovative ideas represented open-ended problems that acted as suggestions or "working hypotheses" guiding further inquiry. This observation leads up to my main finding: *Innovative ideas emerge and unfold through a collective improvisatory process driven by the participants' improvisation on an open-ended innovative idea*. The process displays an underlying non-linear divergent-convergent system dynamics characterized by the alternation between idea generation and idea selection. The participants' inquiry into the innovative idea reveals the need for exploring Which/How/What-questions. This investigation, in turn, aims at creating new ideas in terms of solutions to these open-ended problems (divergent phase). The solutions are then subject to evaluation and selection (convergent phase), triggering a new search for solutions to the chosen innovative ideas, and so on in an ongoing flow of inquiry. The collective inquiry gradually transforms the innovative into newer ideas bearing more or less resemblance to the original one.

Third, the finding that innovative ideas emerge and unfold through a collective improvisatory process is in line with the MIRP researchers' observation that innovations are not initiated on the spur of the moment by a single entrepreneur. Innovative ideas are born and developed through an ongoing dialogue and collective reflection involving several people. Finally, my observation of the underlying non-linear system dynamics shows that the traditional understanding of innovation as a linear progression from idea generation to

[465]Most probably, the MIRP researchers define the ideas appearing in plans preceding the initiation of innovation projects as the "innovative" ones.

idea development is not adequate. Indeed, the transformation of innovative ideas into concrete reality requires continuous problem setting and the creation of new ideas, meaning idea creation and idea development are intertwined activities in an ongoing flow of inquiry. For this reason, the MIRP researchers' distinction between idea generation (initiation period) and idea development (development) represents a great simplification.

My findings are based on the analysis of a section of the innovation journeys. To what extent do they apply to the remaining parts of the case projects? Likely, the remaining innovation journeys display similar process characteristics to the periods highlighted in this chapter. From the above discussion, it is evident that the sections called attention to should be regarded as moments cut out of an ongoing flow of activities. As such, I argue that the "final" ideas visualized in Chapter 11.2.2 neither demarcate the end of inquiry nor introduces a quite different type of process. Like all the other ideas displayed, the "final" ideas are simply those ideas guiding further inquiry; they are the innovative ideas people improvise on from that point in time. Therefore, I assume that my findings apply to the innovation journey as a whole.

11.3 How Do People Collectively Create New Knowledge in Innovation Projects?

The findings derived from the analysis of how innovative ideas emerge and unfold over time shed light on how people collectively create new knowledge in innovation projects, that is, in highly ambiguous, uncertain, complex, and uncontrollable situations. In sum, the analyses show that people co-create new knowledge through an ongoing improvisatory process driven by the joint improvisation of an innovative idea (project theme). That is, when the players venture into an inquiry, they start improvising on an open-ended innovative idea (project theme) like jazz musicians improvise on a song. The innovative idea, including for instance proposed plans for progress and scheduled steps for research activities, guides the further inquiry. The project members' problem setting, that is, their naming and framing of the innovative idea (Schön, 1983), provide the moderate constraints (form, ref. Weick, 1998) needed for guiding people to a common place while simultaneously allowing them the freedom to approach the problems in ways that make most of their competence. The knowledge creation displays an underlying non-linear divergent-convergent system dynamics characterized by the alternation between idea generation and idea selection. The participants' inquiry into the innovative idea reveals the need for exploring Which/How/What-questions. This investigation, in turn, aims at creating new ideas in terms of solutions to these open-ended problems (divergent phase). The solutions are then subject to evaluation and selection (convergent phase), triggering a new search for solutions to the chosen innovative ideas, and so on in an ongoing flow of inquiry.

Moreover, my data clearly shows that the knowledge creation is a social process characterized by an ongoing dialogue, collective reflection, and collaborative efforts involving several different specialists. Another salient finding is that people are in continuous dialogue with their material, e.g. the innovative idea, the What/How/Which-questions, the knowledge, skills, thoughts and opinions of people invited to collaborate in the projects, various explicit information, unexpected cues etc. They are in a reflective conversation with the new and unique situation (Schön, 1983). People listen to their own contributions and to the offerings provided by others, building on them. They are open to unexpected cues, welcoming them in the same way jazz musicians respond to the introduction of new chords or phrases. Similarly, they emphasize the concept of bricolage, the art of making use of whatever is at hand (Barrett, 1998). Individual and collective improvisation on the material directs the joint inquiry. Project participants are not necessarily able to look ahead at what they are going to play, but they look behind at what they and others have performed earlier. Each new step in the inquiry can thus be shaped in relation to what has gone before. It follows that the collective knowledge creation is a guided activity, relying on retrospective sense-making as form (Weick, 1998).

So, summing up, I find that in innovation projects people collective create new knowledge through a collective improvisatory process driven by the participants' joint improvisation on an innovative idea. The process is characterized by a close interplay of and collaboration between different specialists, mutual appreciation of individual contributions, reliance on retrospective sense-making as a form, process awareness, attention to the concept of bricolage, recurrent cycles of divergent-convergent activities, and emphasis on ongoing dialogue and a collective reflective practice.

11.4 Is the Need for Creativity Most Prominent in the Early Periods of Innovation Processes?

In Chapter 5.6.5 I presented the issues highlighted in Chapters 11.2 and 11.3 as proper sub-questions in light of the question of whether the need for creativity is most prominent in the early periods of innovation processes. I emphasized the importance of highlighting the question in terms of both the common definition of creativity (idea generation) and my broader definition of creativity as the individual and collective capacity to define and solve open-ended problems in a novel, appropriate way. More specifically, I claimed that an analysis of how innovative ideas emerge and unfold over time would provide useful knowledge of whether the creation of new ideas primarily takes place in the early periods of innovation projects. Similarly, I argued that an investigation into how people collectively create new knowledge in innovation projects would shed light on whether innovation requires people to define and solve open-ended problems throughout the innovation journey, or just in the beginning of it. *My data clearly points out that innovation calls for creativity throughout the entire process*. First, the analysis of how innovative ideas emerge and unfold over time shows that innovation is a collective improvisatory process driven by the participants' improvisation on an open-ended innovative idea. This process is characterized by recurrent cycles of idea generation and idea selection, demonstrating that innovation is not a linear process wherein the need for idea generation is most prominent in the beginning. This finding demonstrates that the traditional sequential creativity-innovation model is not adequate. The analysis of how people collectively create knowledge in innovation projects sheds further light on this finding by illustrating that the unpredictable, uncontrollable nature of innovation processes requires regular framing and reframing of problems (e.g. innovative ideas). The project participants' joint improvisation on the innovative idea implies a recurrent need for exploring open-ended Which/How/What-questions, and this investigation, in turn, aims at creating solutions to these problems, and so on in an ongoing flow of inquiry. This underlying non-linear divergent-convergent system dynamics clearly indicates that the need for creativity in terms of the capacity to define and solve open-ended problems in a novel, appropriate way is not most important in the early period of innovation processes. Thus, I conclude that *the need for creativity is not most prominent in the early period of innovation processes*.

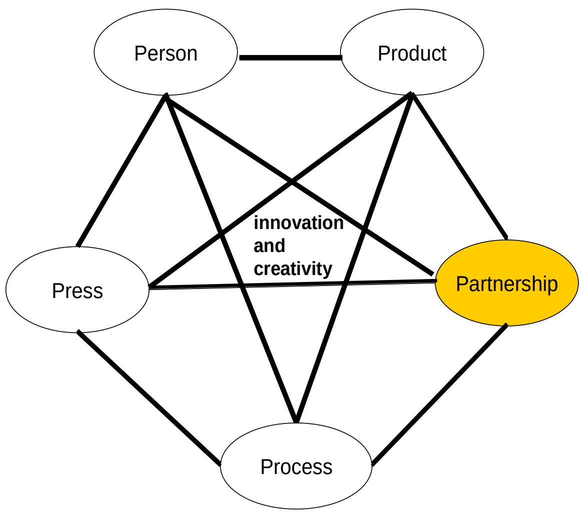
My finding that innovation calls for creativity throughout the entire innovation journey is important. By demonstrating that the traditional linear model of innovation is not adequate, it challenges the prevailing assumption that innovation success primarily depends on the ability to identify creative people with creative ideas. Indeed, individual creativity is important.[466] However, my study of the *Process* facet of innovation and creativity suggests that the project participants' *collective* capacity to improvise and keep inquiry moving throughout the unpredictable, uncontrollable innovation journey is a more significant criterion of success. As such, the orchestration of a continuous, fruitful interplay of participants seems to be a major challenge in innovation projects.

[466] See Chapter 8 highlighting my empirical data in light of the *Person* facet.

Chapter 12 Analysis and Discussion of the Partnership Facet of Innovation and Creativity

12.1 Introduction

In this chapter I analyze and discuss my empirical data in light of the *Partnership* facet of innovation and creativity, that is, characteristics of innovation as a social, collective achievement. I structure the analysis and discussion according to the facet-specific research questions proposed in Chapter 5.7 (see below). In Chapters 12.2 through 12.5 I shed light on characteristics of innovation as a collective, open-ended activity by means of a systems of innovation analysis of the Omacor™ project. For considerations of space, and because the Omacor™ project alone represents a rich, comprehensive amount of empirical data, I focus on this project only. I Chapters 12.6 and 12.7 I highlight characteristics of creativity as a collective capacity by means of network approaches. Here I present networks found in the Omacor™ project, the "Die Life" project, and the "Bearing Channel" projects because these projects provide the most prominent examples of the influence of various formal and informal networks.



Research Questions in Terms of the Partnership Facet of Innovation and Creativity:

Which types and compositions of competence are important to succeed with innovation?

> *Which activities by which actors/organizations are important to succeed with innovation?*
>
> *Which institutional rules influence the activities of the actors/organizations in carrying out activities in innovation projects?*

How do networks influence collective creativity in innovation projects?

> *How and why do people use and create networks in innovation projects?*

12.2 The Omacor™ Project as a System of Innovation

12.2.1 Introduction

Chapter 6.5 presented a systems model of pharmaceutical product development (see Figure 12.2.1).

The model, which is grounded in my empirical study of the Omacor™ project, portrays pharmaceutical product development as a system composed of two interrelated main challenges: The "pharmaceutical" challenge (in pink), and the "commercial challenge" (in green). The "pharmaceutical" challenge is the challenge of obtaining *marketing authorization* for a therapeutic pharmaceutical (in pink), that is, the license to sell and market the drug to patients and physicians. The "commercial" challenge concerns the efforts of transforming the approved pharmaceutical product into a *commercially* successful product (in green). Here, patents are decisive, because the period of validity of patents represents the period of time for recovering the cumulative investment in developing the therapeutic pharmaceutical (illustrated by the zigzag arrow). The dynamic interactions of the "pharmaceutical" and "commercial" challenges represent the very essence of pharmaceutical product development.

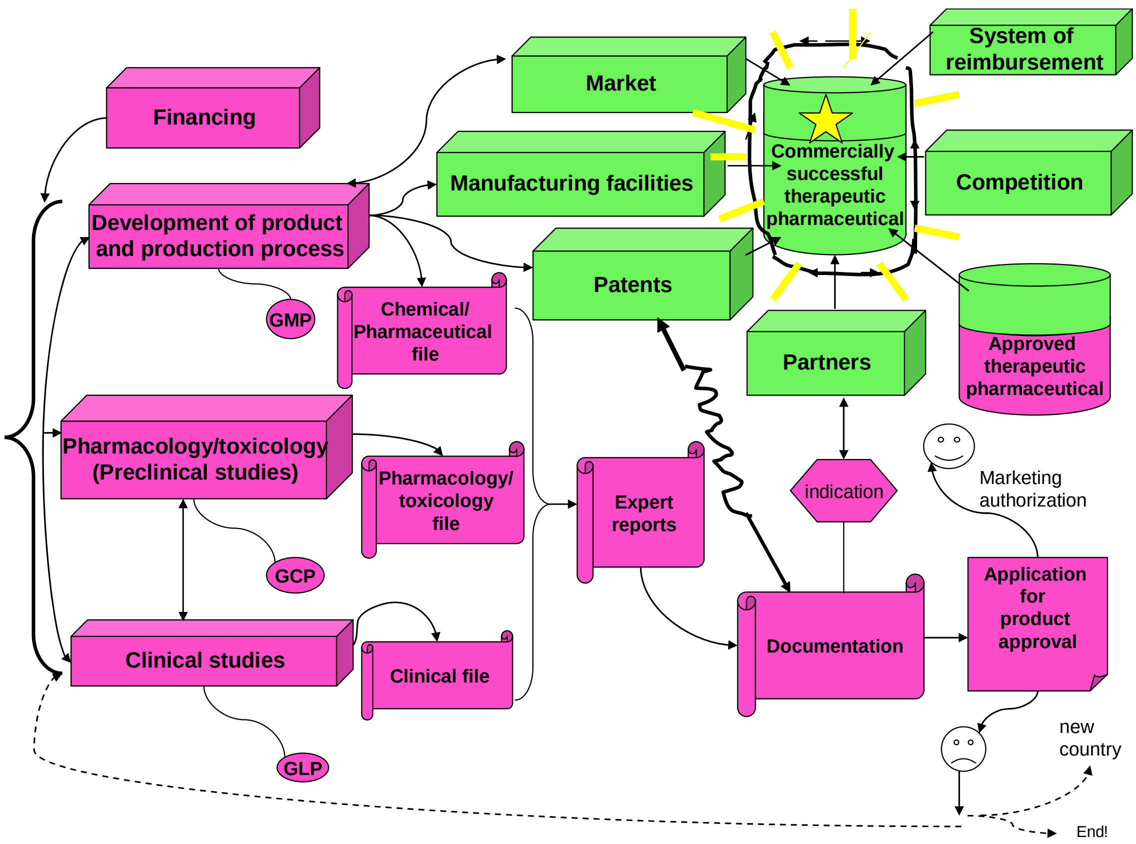


Figure 12.2.1 A Systems Model of Pharmaceutical Product Development

The aim of the Omacor™ project was to develop a new therapeutic pharmaceutical based on omega-3 fatty acids. My knowledge of this *function*[467] guided the delineation of the system boundaries in the sense of helping me identify important factors influencing the creation and implementation of a commercially successful drug. As such, the system of innovation model presented in Figure 12.2.1 calls attention to the *determinants*[468] of innovation processes within the field of pharmaceutical product development.

However, the systems model does not show *all* the important factors in question.[469] It also reflects several contextual assumptions. For the sake of simplicity, Figure 12.2.1 illustrates the system of pharmaceutical product development related to *one* indication (treatment of a disease) in *one* country only. This will hopefully make the model easier to understand. For similar reasons, the model visualizes important activities, artifacts, and institutions, but leaves relevant actors such as regulatory authorities and project owners out. Moreover, the systems model does not specify that *partners* may be of little relevance for

467 Ref. Edquist, 2005
468 Ref. Edquist (2005)
469 Clearly, apart from the simplifications mentioned in the following section, I assume that there are several other factors that are relevant in pharmaceutical product development that my study does not account for.

pharmaceutical companies with in-house marketing departments, and it does not account for the opportunity for so-called *off-label* prescriptions in the US.[470]

Furthermore, the systems model should be read as a dynamic process field. Even though some linear steps are displayed, focus is on the *interaction* of the various sub-activities that together constitute the overall innovation activity as a whole. Finally, I emphasize that my conceptualization of a "pharmaceutical" and a "commercial" challenge represents a simplification that does not take the full complexity of innovation into account. Therefore, my division of the innovation system into two separate parts or challenges should not be taken too literally; it should be regarded as an analytic approach facilitating discussion on the system components and their relationships.

In the following I make an in-depth presentation of the Omacor™ project as a system of innovation.[471] I present the system components pertaining to the "pharmaceutical" and "commercial" challenges respectively, and point to important relationship between these.[472]

12.2.2 The "Pharmaceutical" Challenge

The "pharmaceutical challenge" represents the set of interrelated factors needed to obtain marketing authorization for a therapeutic pharmaceutical (the pink area in Figure 12.2.1). To obtain marketing authorization, the quality, safety, and efficacy of a product have to meet comprehensive documentation requirements for pharmaceutical products. The requirements apply to three main activities in pharmaceutical product development: *Development of a therapeutic pharmaceutical and a production process*, *pharmacology/toxicology (pre-clinical studies)*, and *clinical studies*.[473] These activities have to be conducted in accordance with the directions of Good Manufacturing Practice (GMP), Good Laboratory Practice (GLP), and Good Clinical Practice (GCP), respectively. As such, these *institutions* (Ref. Edquist, 1997; 2005) play a prominent role in pharmaceutical product development.

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[470] Once a drug has been approved by the FDA for an indication and then marketed for that indication, physicians are allowed to prescribe the drug for any other indication if there is reasonable scientific evidence that the drug is effective for that indication. These uses that have not been approved by the FDA are the off-label indications.

[471] Most of my empirical data from the Omacor™ project concerns the component denoted Development of product and production process. Therefore, the review of activities relevant for this part is far more comprehensive than the description of the other components of the model.

[472] For practical reasons, I highlight the component Manufacturing facilities, pertaining to the "commercial challenge", in connection with the presentation of Development of product and production process pertaining to the "pharmaceutical challenge".

[473] For a further description of these activities, see Chapter 6.5.

When the *chemical-/pharmaceutical-*, the *pharmacology/toxicology-*, and the *clinical files* are completed, independent experts examine the files. If the experts approve the files, they write expert reports, recommending approval for marketing authorization. If the regulatory authorities determine that there is enough evidence to approve the therapeutic pharmaceutical for the *indication* (treatment of the disease), the indication becomes a labeled indication for the drug. The manufacturer is now allowed to sell and market the product within the approving country.

Financing

From a financial point of view, the pharmaceutical challenge represents the costly, comprehensive, and time-consuming documentation required to obtain marketing authorization for a new therapeutic pharmaceutical. As a consequence, financing of the work needed to deal with the pharmaceutical challenge was an important activity in the Omacor™ project, as previously suggested. For instance, Chapter 8 showed how the actions of a *project champion* with strong persuasion skills positively affected the allocation of necessary financial resources in the Omacor™ project. However, I postpone a further outline of the issue of financing to Chapter 12.6 where I shed light on strategic actions taken to influence people with decision-making authority.

Development of Product and Production Process

The origin of the Omacor™ project was a research project aimed at developing a process for extracting enzymes from fish waste. The process provided enzymes, but also a fatty by-product which raised the question of what to do with it. The project manager Sigurd Gulbrandsen applied to Norwegian research groups to discuss the possibility of a commercial utilization. Among others, he contacted *Bernt Børretzen*, an organic chemist he knew at the Hydro Research Center in Porsgrunn. Børretzen responded immediately, suggesting that the omega-3 fatty acids in the fat could form the basis for a high-concentrate omega-3 "heart medicine". Gulbrandsen then wrote a document on fine chemicals from fish waste, reporting that the unsaturated marine fat had properties that could be made use of in therapeutic pharmaceuticals. He also called attention to another group of fatty compounds that could be used in fish food.[474]

[474] Finkjemikalier fra fiskeavfall. Vurderinger ved start av prosjekt i Analytisk avdeling. 1984-11-22

Gulbrandsen and Børretzen presented the project idea for the Hydro top management at the Corporate Center in Oslo. The concept was well received, and Gulbrandsen could go on, preparing for the initiation of the “Fine Chemicals from Fish Waste” that was to begin in January 1985.

At The Hydro Research Center in Porsgrunn, Børretzen started to look for a co-worker. He got in touch with Harald Breivik in the Analytical Department who found the idea highly interesting. In August 1984 the project idea was discussed at a meeting where, among others, the head of the Analytical Department took part. He was very excited by the idea of involving the department, generally perceived as a service organization, in the project. As a consequence, contrary to the usual practice, Breivik was allowed to start preparing the project even though they had no budget for it at that time.

Determination of Commercially Interesting Fine Chemicals

During the fall of 1984, Breivik joined Gulbrandsen and one of his colleagues for a visit to The Fisheries Research Center. Breivik was introduced to the ensilage technology, and he discussed the question of which types of fine-chemicals were present in the fish fat with members of the ongoing research project. Breivik also made some chemical analyses, prepared for the start-up of the project and made a preliminary literature survey aimed at exploring areas of use, prices, market, etc. for some of the fine chemicals expected to be found in the fat phase of the ensilaged fish waste. The relevant groups of fine chemicals were *unsaturated fatty acids, steroids/cholesterol,* and *tocopherol* (vitamin E). Among these, the market for unsaturated fatty acids appeared to be the most promising. During 1985 the initial focus on fine chemicals was narrowed down to cholesterol and the omega-3 fatty acids EPA and DHA. This new focus triggered a discussion on the relative importance of EPA compared with DHA, an issue that, in turn, was closely linked to the question on which raw material to use: Should DHA be given priority, implying the use of North Atlantic fish oil, or should EPA play the main part, meaning application of “foreign raw material”? During 1986 the case went in favor of EPA and the latter point of view.[475]

[475] Project members still emphasize that choosing EPA was not the only factor influencing the decision to leave fish waste as a raw material. Project members soon realized that the amount of ensilaged fat produced in Tromsø was not sufficient for their activity. In addition, the EPA-decision was in line with the process technology used by Martens, the first fish oil plant Hydro acquired. Here, Norwegian fish oil could not be used.

Two Components of the Production Process: Esterification and Urea Precipitation

At the end of 1985, Breivik, Børretzen and one of their colleagues at the Hydro Research Center in Porsgrunn applied for a patent for a refined fish oil concentrate and the production process for the same, producing high-concentrates of EPA and DHA, cholesterol, and a by-product called urea-adducts. *Esterification* and *urea precipitation* were main components of the patented production process.

Esterification is about transforming fatty acids from their natural state into esters through a chemical reaction between the fatty acids and alcohol (methanol/ethanol). For a long time researchers had known that the easiest way to separate fatty acids was by means of extraction or distillation when the acids appeared in the form of esters, for instance as methyl or ethyl esters.[476] For the Hydro researchers, the question of which alcohol to use became a point of concern. Initially, they started using methanol, but through discussions that also involved external leading researchers, they chose to switch to ethanol, because the human body is not particularly responsive to methyl esters. From a process point of view, the use of ethanol implied that the researchers had to modify the production process. In addition, it became more difficult to meet the strict requirements of GMP. As a project member explained:

> *…Some countries do not allow people to handle pure ethanol without supervision. The ethanol is supposed to be accounted for – counting kilograms going in and out. And that is not easy when you distillate, because some of it flashes up into the air…*

Urea precipitation is a filtration method in which urea is added, crystallizing and attracting unwanted substances. The method was invented in the 1940s but the Hydro researchers were the first to adopt it, adapting it to fit their case. The use of urea implied two main challenges. The first challenge concerned its hygroscopic character. The usual type of urea, used in fertilizers, was coated to become water-resistant, and could thus not be used because it did not dissolve. In addition, the coating process involved the use of components that could not be present in a medicinal product. As a consequence, Hydro researchers had to find proper non-coated urea and develop solutions for handling it. Hydro had produced non-coated urea in the past, meaning the researchers could easily get relevant assistance from local competence people. On the other hand, they had to look to Germany, the Netherlands, and France to find a relevant producer. The researchers made investigations

[476] http://ep.espacenet.com/espacenet/ep/en/e_net.htm
Patent number: EP255824

and contacted a few suppliers, experimented on supplier's products and worked out new specifications for components to be added. In this way, the Hydro researchers succeeded in finding the best and simplest offer for their purpose.

The second challenge concerning urea was the large volume of a by-product ("the UFF"). "*The work aimed at finding a possible use for it was quite a comprehensive task in itself*," a project member remarked, explaining:

> *… From a precipitation or process point of view, re-using the urea… would have been an advantage. However, we realized that this solution was difficult; it implied the construction of an entire system for handling the urea. We concluded that we had to develop a short-term solution aimed at finding someone who could take care of the UFF. And, actually, through the Hydro-system we got in touch with a small English fertilizer company that wanted to buy the stuff…*

Urea precipitation was *one* of several possible methods for producing an omega-3 high-concentrate. In the Status Report of June 1985 Breivik argued in favor of continuously looking for other ways to produce DHA/EPA and cholesterol from ensilaged fat. Elaborating on the issue in retrospect he said:

> *…The purpose of this work, the way I saw it, was to build a tool box consisting of different tools. The problem with fatty acids is that marine oils contain a large number of component groups. One tool removes one group, some other another. Thus, you need a combination of technical methods to develop a product (…) It is quite complicated to obtain a substance that contains EPA and DHA only, and get rid of the other stuff…*

Ergo, the development of an appropriate production method for a "pure" omega-3 concentrate was a great challenge.

Mixed Omega-3 Concentrates versus Pure Products

The efforts directed at developing proper production methods were linked to the question of whether a *mixed* EPA/DHA concentrate, or *pure* EPA and DHA concentrates should be developed. The discussion reflected two interrelated questions: 1) Should Hydro go for a nutrition supplement, or a therapeutic pharmaceutical? and 2) What level of purity (concentration) was needed to meet the requirements for therapeutic pharmaceuticals? Through urea precipitation, the researchers were able to produce a concentrate that typically consisted of 28 percent EPA and 45 percent DHA.[477] This product they labeled the "raw

[477] "Produksjon av ω3-konsentrater, EPA, og DHA. Status August 1986" 1986-09-02.

concentrate”. By means of another method they managed to isolate some grams of pure 90 percent EPA and 90 percent DHA from the raw concentrate. In the Status Report of December 1985 Breivik stated that the EPA/DHA concentrate could be sold as a nutrition supplement whose quality was at least equivalent to the ones that were already present in the Japanese and American markets, whereas the EPA and DHA concentrates had sufficient purity to become a therapeutic pharmaceutical product. In late 1986, Hydro-researchers were able to produce a few kilograms of a 90 percent mixed EPA/DHA concentrate, that is, an additional omega-3 candidate of “pharmaceutical quality.” Having developed one mixed and two pure 90 percent omega-3 concentrates, the researchers agreed to base the final decision regarding mixed/pure products on market surveys.

Breivik had previously pointed out that the production of pure concentrates might prove to be expensive compared to the production of a mixed concentrate that could be produced in large quantities at relatively low cost. One decided to continue the activity on both mixed and pure products. The production of pure products was seen as important regarding the individual efficacy of EPA and DHA. This activity was given increased priority toward the end of the 1980s, resulting in several patents, but this project was terminated in the 1990s.

Scaling- Up and Manufacturing Facilities

In late 1985 progression was faster than expected with a corresponding doubling of project expenses. Now Hydro researchers wanted to focus on developing an efficient method for producing several kilograms of 90 percent EPA and 90 percent DHA for clinical testing. Scaling up the production of the EPA/DHA raw concentrate was thus essential for the further progress of the project.[478] The researchers planned to do the scaling-up in two steps. The first step was a small-scale production providing some kilos for clinical tests. Next, pilot plant production was planned, supposed to be the last step before manufacturing scale. The goal was to be ready for production of an omega-3 concentrate, cholesterol, EPA, and DHA in 1987.[479]

The scaling- up efforts were related to two stages in the production process: The urea precipitation step providing the raw concentrate, and the following process for isolating high-concentrates of EPA and DHA. For the second stage, two different technologies were considered as relevant for the isolation of pure EPA and DHA from the raw concentrate.

[478] ”Finkjemikalier fra fiskeavfall. Status ved utgangen av 1985”. 1985-12-19

[479] Finkjemikalier fra fiskeavfall. Status oktober’85 med tanke på samarbeide med Kjemiteknisk avdeling.” 1985-10-21

Hydro researchers produced the first grams of pure EPA and DHA in a "mini-pilot" plant at the Research Center by means of in-house technology. This production method became the basis for assessments of full-scale costs, prompting the conclusion that another technology should be given priority for the time being. To make closer investigations into this other technology, researchers from the Hydro Research Center's Mechanical Engineering department, Porsgrunn, were engaged in the work. Project manager Breivik and co-workers made contact with several international firms, visiting them to establish possibilities for contract production and learn about the firms' production technology and know-how. They decided to collaborate with a world-renowned French professor, and to perform pilot plant production at "his" firm. The results obtained here were promising.

The first phase in scaling-up the production of the raw concentrate was carried out by means of pilot plant equipment available at the Hydro Research Center's Petrochemical department, Porsgrunn. As the production capacity could not meet the material demands for pre-clinical/clinical studies, the project team had to look elsewhere for suitable equipment with sufficient production capacity. People from the Hydro Research Center's department for Chemical Engineering and Mechanical Engineering, and Hydro Engineering became engaged in this work. Marianne Harg headed the subproject, collaborating closely with Breivik and other members of the main project.

In general, scaling-up is a complex task. For the Hydro researchers the scaling-up efforts were even more difficult because of the "unpredictable" nature of fish oil. As Harg recounted:

> *…Issues on scaling-up are always difficult to handle, and you never quite know what sort of things that can actually be scaled-up…You always have to try things out, and the chances for wrong choices are great. Things may work well on a small scale, but not on a large scale, and the other way around. And then there are different types of equipment for the different scales. In addition, other types of equipment are available for the different scales. For instance, in a lab scale, glass equipment may be used, but large scale requires equipment made of steel. Thus, things are visible on a small scale, but not on a large, etc. Making mass balances for the substances we were working with were very difficult. Working on better-described processes is somewhat easier. In our case, we did not know much about how the material did behave, and the raw material varied from time to time…*

The scaling-up work started in February 1986. The work was focused on practical process design, unit operation types, and equipment. These investigations formed the basis for a preliminary study aimed at developing a cost estimate for a full-scale production plant, expected to go into production in the beginning of 1988.[480] At this time, no decision was made concerning the location of the plant.

The preliminary study involved two main issues: Questions of equipment, and the requirements of GMP. Hydro researchers had to find suitable equipment for the specific purpose of developing a therapeutic pharmaceutical product. They made several visits to look at equipment and relevant plants, and they also visited equipment suppliers. The preliminary study represented a great challenge, not least because the researchers lacked competence on pharmaceutical product development. "*It was a formidable task, because none of us were familiar with this kind of equipment. We did not know what to ask for, either*", Harg commented, continuing:

> *…Both Good Manufacturing Practice and Good Laboratory Practice was unplowed ground at that time. There was really no one in Hydro who was familiar with these regulations. Some had some theoretical knowledge, but no one had* ***practical*** *experience with these things: No one had made protocols - procedures for monitoring GMP-based processes…We felt like we were back to square one. At the same time, we had to write a complete protocol describing what to do, how do document it, what precautions to take concerning the trial production at the different locations. That was very difficult- maybe the greatest uncertainty during the process - because we knew that our documentation was essential for the application for product approval. That is not easy when you don't know what to do! Thus, it was quite a headache, and we hardly had anyone to consult, because there was almost no one that was competent in this area, particularly not in Norway. But, we managed quite well, though. We had some misses, but our results were good enough, and we learned a lot...*

The search for firms that sold production capacity (trial production plants) was another challenge: "*We did not know what trial production was, either*", Harg remarked. The researchers had to identify potential trial production firms. They studied different journals and acquired relevant information through acquaintances. They also asked the library at the Research Center to make some screening. The efforts resulted in a long list of names of potential firms, and the Hydro researchers made contacts in order to establish which firms were actually interesting and worth visiting. Harg and her colleagues visited several companies in Europe to discuss the possibilities for trial production. "*That was really an exciting phase. We learned a lot through inspecting their equipment and discussing how the process could be carried out*", Harg commented.

[480] "Produksjon av ω3-konsentrater, EPA og DHA. Status august 1986." 1986- 09- 02

The Acquisition of Two Fish Oil Companies

In 1987 and 1988 Hydro acquired two Norwegian fish oil companies that happened to be for sale. Before describing these acquisitions, I briefly present two persons who strongly influenced Hydro's decision to enter into the fish oil business.

Since the summer of 1985, Hans Krokan had been head of the Hydro Research Center's department of Biotechnology. He was a doctor of medicine with a PhD in biochemistry who had worked at the University of Tromsø for several years. Responsible for the biotechnological product portfolio, Krokan concluded that new projects were needed in order to promote activity within his department. He soon got to know about the omega-3 research at the Research Center, finding it to fit well with his plans.

In the summer of 1986, the Agriculture Business Unit got a new Vice President. The Vice President had previously headed a large fish meal company and was familiar with research on fatty acids and the fish oil and fish feed industries. As the new head of the fish farming and fish feed activities, the Vice President was interested in exploring new opportunities within the field of biotechnology. He found the Omacor™ project highly interesting, not least in light of the prospect for synergy with other marine activities.

According to project members, Krokan and the Vice President became a strong team, able to exert considerable influence on the further path of the project. Krokan and the Vice President discussed visions related to omega- 3 and other fish activities. They agreed on the idea of having the complete chain from fish farming, fish oil intended for nutrition supplement, and an omega-3 high-concentrate as a therapeutic pharmaceutical product. Moreover, based on his trade knowledge, The Vice President argued in favor of using commercial fish oil rather than fish waste for the production of an omega-3 medicine.[481] Krokan shared this opinion. So, the announcement that the fish oil company JC Martens in Bergen was for sale was attractive news to the Hydro managers in question.

The Vice President, Krokan, and Breivik made a visit to take a closer look at the production facilities. Among other things, the process technology called *Molecular Distillation* was of particular interest regarding further process development. In the end of 1986 Hydro bought JC Martens in competition with Jahres fabrikker, JC Martens' main competitor. A year later, in 1987, Hydro acquired Jahres fabrikker that was for sales due to financial difficulties in the mother company. Through these purchases Hydro became one

[481] Other Hydro people emphasize that the fish waste itself was never intended to be the basis for a commercial omega- 3 activity: "*That's obvious*!" one of the project members stated. From his point of view, the fish waste only represented merely the "point of departure and the original idea" related to the problematic fat.

of the largest fish oil companies worldwide, bringing the omega-3 project a "*quantum leap forwards*," as a project member put it.[482]

The acquisitions of Martens and Jahres boosted advantages related to the development of Omacor™, and Hydro gained access to relevant process technology such as molecular distillation. This technology represented a turning point for the efforts for scaling up the production process. Hydro researchers aimed at developing a 90 percent "mixed" EPA/DHA concentrate, but were not able to produce it on a full production scale. "*Then suddenly*", as Breivik commented, "*through Martens' molecular distillation technology we were able to produce an 85 percent concentrate in large quantities. Now it was laughter and joy!* The initial goal of a 90 percent concentrate was then redefined to an 85 percent concentrate, and the efforts directed at developing the 85 percent concentrate (*k85*) were given high priority from 1987 on.[483]

The fish oil companies provided considerable competence on fish oil and access to high-quality raw material. In addition, both companies produced omega-3 low-concentrates as nutrition supplements. The sale of these products became an important part of the omega-3 activities in Hydro. The acquisitions were also motivated by the possibility of obtaining a location where Hydro could start building a manufacturing plant. The initial plan was to use the location of JC Martens in Bergen, but it turned out that this place was not fit for an industrial expansion. Jahres fabrikker, the other hand, was considered a suitable site. Accordingly, acquiring Jahres appeared as a much better alternative than maintaining the competitor relationship, and the need for an industrial building site strongly influenced the decision to purchase Jahres fabrikker.

However, neither the installations at JC Martens nor at Jahres could immediately serve as manufacturing facilities for the production of *k85*. The molecular distillation installation at Martens had to be modified, and new production lines had to be installed before the companies could play a major role in the manufacturing of *k85*. As a consequence, the path from the acquisitions of the fish oil companies to the new manufacturing plant in Sandefjord completed in 1993 involved a set of different ways to organize this production.

[482] Characteristically, the title "Fine chemicals from Fish Waste" was changed to "Omega-3 Concentrates". The company Marine Biochemicals, founded on the enzyme production from fish waste, was terminated in 1990. Thus, as a curiosity, "*the end of the story was that we focused most on the fat fraction contrary to our initial plans because it turned out to be of greatest interest*," as Gulbrandsen remarked.
[483] *K85* was the unofficial name of the 85 percent omega-3 concentrate that became Omacor™.

The manufacturing process and the location of the different process steps in 1989/90 and in 1992, respectively, are shown in Figure 12.2.2.[484] Since the mid-1990s, all manufacturing steps except encapsulation have been performed at the manufacturing plant in Sandefjord. To have all but one of the manufacturing steps in one single site represented an improvement from manufacturing both at JC Martens and Jahres in the beginning of the 1990s. At that time, urea precipitation and esterification was performed at Jahres, Sandefjord, while the molecular distillation steps were carried out at JC Martens, Bergen (Ref. Figure 12.2.2). This way of organizing the production implied "*a lot of logistics*" At the same time, this organization represented a great step forward compared to the initial stage in the late 1980s. As Marianne Harg put it:

> *…When the trailer trucks were completely stuck due to winter storms in the Norwegian mountains, or were jerked from side to side at the cargo ships to Stavanger, it was not easy task to perform the manufacturing according to the plans!..*

Clearly, in the late 1980s the production of a batch[485] was a long process with several critical stages. It took about 10 months from choosing the raw material until the *k85* capsules could be released for clinical studies, and the logistics of the project implied involved several locations and many stages of transport, process steps, and analysis. In the words of a project member, "*We had to watch our steps closely and we needed a steady hand, because we were responsible for the quality of these products. If the substance did not meet the specifications, we had nothing*".

[484] As shown in Figure 12.2.2, the manufacturing process involved several separate steps. First, the crude fish oil was refined and stripped. Simply speaking, refining is kind of a "soap wash" to get the oil cleaner, while stripping is as process for removing some of the lightest components by using molecular distillation. The refined, stripped oil, with a 25-30 percent concentration of EPA/DHA, was then transformed into an ethyl ester by adding ethanol. From this step on, "the process was intended to preserve EPA and DHA," as one of the project members explained. In turn, the 30 percent concentrate (*k30*) was distilled by molecular distillation removing the lightest and most heavy components. The result was a concentrate containing approximately 50 percent EPA/DHA (*k50*). Through urea precipitation, other unwanted substances were removed, turning *k50* into a concentrate of approximately 80 percent EPA/DHA (*k80*). *K80* was then filtered further by molecular distillation, resulting in *k85*, a concentrate consisting of approximately 85 percent EPA/DHA. This step also involved other "purification" methods for removal of environmental pollution and oxidations. Afterwards, *k85* was filled on casks (barrels) where tophocerol (vitamin E) was added as an antioxidant. The final manufacturing step was encapsulation of soft gelatin capsules.

[485] The term *batch* refers to a specific volume

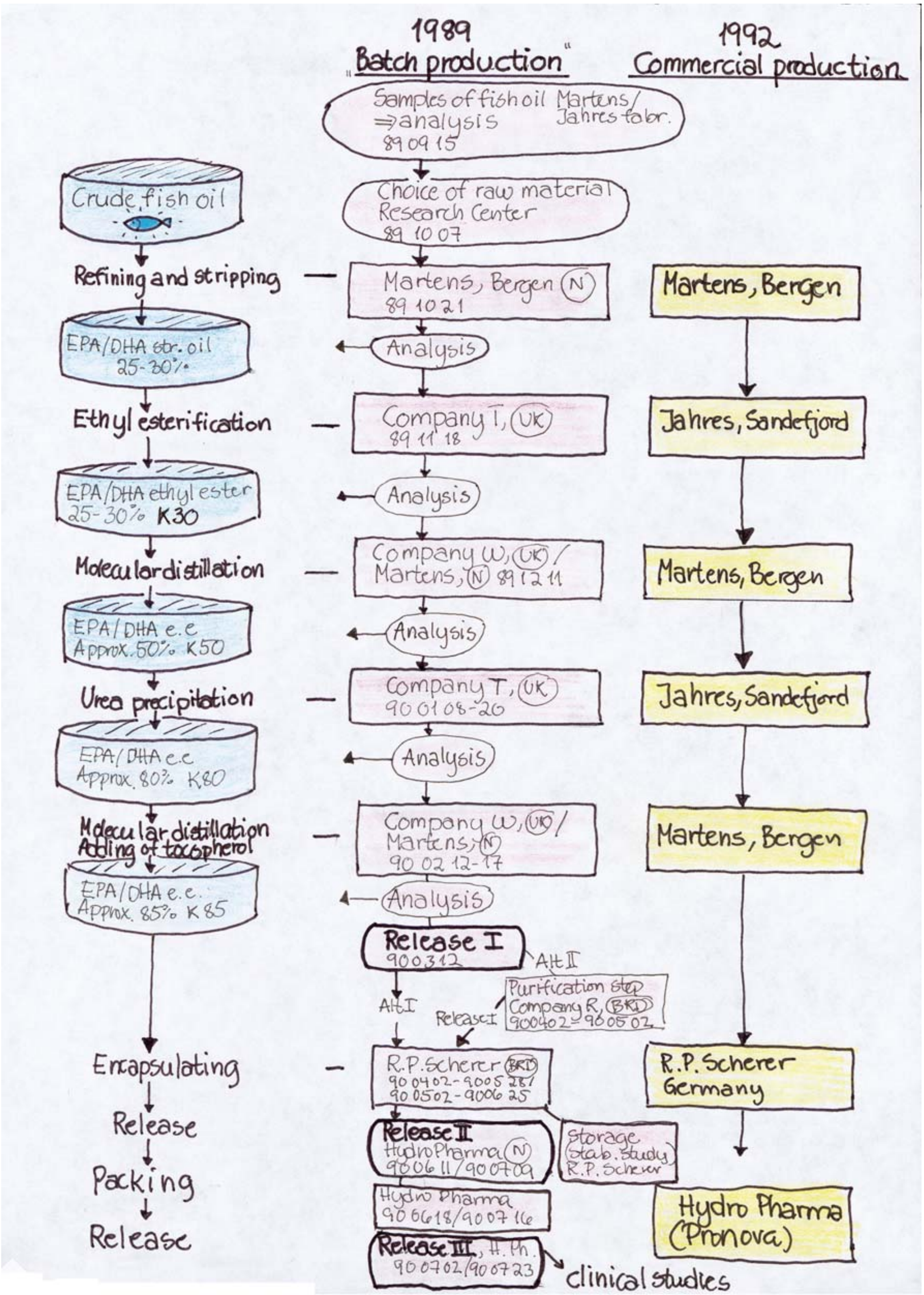

Figure 12.2.2 An Overview of the Manufacturing Process and the Location of the Different Process Steps in 1989/90 and 1992

The GMP requirements implied that project members from the Hydro Research Center, Porsgrunn had to monitor the process steps at the respective production sites. The manufacturing processes were performed by local process workers, but Breivik, Harg, and their colleagues had to write protocols, documenting all relevant procedures and process parameters. They also informed process workers on matters such as quantities of chemical substances to be use used at the different steps. In addition, chemical analysis was important. The Hydro researchers had to make sure that the substance met the specifications for the components in question. At the same time, the researchers had to make sure that process workers were able to perform the same analysis using local equipment when the researchers were no longer present. It required a great effort to calibrate and write analytic procedures that could be followed by others, gaining the same results. The encapsulation step was also a great challenge. The presence of Breivik and his colleagues, co-operating with representatives for the encapsulation company, was decisive for meeting the requirements of GMP.

The researchers succeeded with their efforts directed at obtaining the required product quality. However, some project members point out that the fact that physicians had made appointments for start-up of clinical studies long time before they had ever finished a batch, left no time for process improvement aimed at cost reduction. One of them said:

> *…For several years the project suffered from being tied up with producing substances according to agreements. In this situation you no longer had the chance to make modifications of the product. We should have optimized the production process, because it is expensive. That was never done, because all what we produced was used for clinical studies…*

Despite the great difficulties involved, the researchers succeeded with their efforts concerning the batch production and the GMP requirements.

Providing Product Stability and Reliability

Ensuring product stability and reliability was one of the main tasks in the development of Omacor™. When exposed to oxygen and light, fish oil rapidly turns rancid. In addition, omega-3 fatty acids easily saturate. For these reasons, the *k85* substance had to be protected from oxygen and light during the process and had to be packaged in order to last as long as possible during normal storage.[486] This requirement implied the development of specifications related to a protective packaging system and storage method, and stability testing of the product in accordance with GMP.

[486] Svendsen (1996)

Encapsulation by means of gelatin capsules is widely used for products such as omega-3 concentrates. Gelatin capsules, which are completely filled with oil, provide no headspace of air in the capsules. They also mask the taste of oil, and make the product easy to swallow. However, the manufacturing of soft gelatin capsules is a difficult and comprehensive process compared to the production of tablets. The fact that project members did not have competence in the field added further complexity to the matter. As one of the project members remarked:

> *…The efforts of deciding the proper size the capsules, the consistency of the gelatin and its influence on stability, and the question of whether the capsules should be packed in boxes or blisters, all these matters represented a new world to us…*

The encapsulation process was carried out at a specialist company in Germany, and people from the Research Center had to be present during production of the first batch in order to monitor the process. Among other things, project members had to develop proper ways to handle the substance at the preparative step before encapsulation in the encapsulation machine. One of them explained:

> *…Before starting the process, the oil, being stored at barrels, is weighted and poured into a container that is transported to the production department. We've worked a lot with this weighting step. Because if you start splashing the oil into the container, you may rapidly get an increase in oxidation parameters, and the oil may be damaged before it enters the capsule. Thus, we had to find out how to perform this step in the most careful way, for instance: How long should the weighted oil rest before starting the encapsulation process? How long time could the encapsulation take?...*

Stability studies imply testing the stability of the product under changing conditions, such as temperature and light. The ability to document the actual period of time a product has been stored without being chemically altered, is a major requirement in pharmaceutical product development. In the words of a project member, "If we did not perform this part correctly in accordance with GMP, we would lose a lot of time backtracking these steps". Time was an important element because stability studies have to span at least two years. As a project member explained:

> *…First the capsules are produced. Then they are analyzed, packed, tested again, sent to the wholesaler, and finally delivered to the therapeutic pharmaceutical store. That is a very long chain. So, two years pass quickly…*

The first two-year stability study of *k85* was started in 1987 at a Swedish pharmaceutical company. When the study came to an end in 1989, Hydro researchers realized the company had not performed the study in accordance with the specifications agreed upon. The company had, due to other priorities, reduced the amount of testing and analysis and simplified the testing method. The main results were positive, but since the study had not been performed in accordance with GMP, another study was required, leading to a delay in the documentation process. Another study was required, and Hydro set up a three-year study in cooperation with Hydro Pharma. In 1990 another three- year study was started due to new requirements for documentation.[487] Thus, the work directed at documenting the stability of *k85* was a complex, time- consuming process.

Chemical Analysis

Chemical analysis of *k85* (and the other omega-3 concentrates) and the development of standard methods for such analysis were major activities in the Omacor™ project. The strict documentation requirements of GMP implied a need for reliable analyses. First, the actual content of the omega-3 fatty acids had to be properly documented. Obtaining such documentation was difficult, because fish oils are complex, and because polyunsaturated fatty acids are not stable. Second, one had to make sure that vitamins A and D, which were selling points for food supplements, were removed from the substance. Third, by-products from oxidation had to be determined both quantitatively and qualitatively. A fourth analytical topic was the presence of environmental pollution agents such as dioxin and PCB, representing an issue of rapidly growing public concern. The identification of such "impurities" was far more difficult for natural substances than for synthetic pharmaceutical products.

Furthermore, project manager Breivik and his colleagues recognized that the project team had entered a field in which standardized analytical methods were lacking. Different methods for analysis of omega-3 fatty acids provided different results, meaning analysis results often varied from laboratory to laboratory. In addition, the absolute difference between results from different test procedures normally increased with increasing concentration of the object of analysis.[488] This was particularly unfavorable in light of Hydro's aim of developing an omega-3 *high*-concentrate. Breivik also discovered that some

[487] Svendsen (1996)
[488] "Validation of a Method for Gas Chromatographic Analysis of Eicosapentaenoic Acid and Docosahexaenoic Acid as Active Ingredients in Medicinal Products" (Tande, Breivik, and Aasoldsen) JAOCS, Vol. 69, no.11 (November 1992)

firms used this situation deliberately to bring up omega-3 values in their products to win market shares. In this connection, he also noticed that omega-3 products were suffering from decreasing interest and a bad image due to a great number of low-quality products in the market.

Breivik concluded that the lack of standardized analyzing methods for omega-3 fatty acids might cause misunderstandings and excess work regarding collaborating partners and the documentation efforts.[489] As a consequence, he spoke in favor of taking active part in efforts directed at the development and definition of standard international methods of analysis for omega-3 concentrates.

The chemical analysis work was carried out by several Hydro researchers collaborating closely with external national and international competence groups. At the Hydro Research Center in Porsgrunn, both the Analytical department and a new Lipid Laboratory dedicated to work solely on analysis of omega-3 products were engaged in these efforts. Arranging “Analysis meetings” and inter-laboratory tests became important strategies related to the efforts of developing standard analysis methods. Hydro researchers were also invited to participate in round-robin tests. Within a few years the Hydro researchers managed to develop methods that were published in one of the leading US journals in the field, and a European expert group approved the methods.[490]

Pharmacology/Toxicology (Pre-Clinical) and Clinical Studies

Hans Krokan, the head of the Department of Biotechnology and one of his colleagues organized the first pre-clinical studies related to the Omacor™ project in late 1986. The pre-clinical studies were performed at the University of Oslo and at an English contract laboratory because Hydro had no appropriate in-house facilities. Hydro researchers designed protocols and monitored the studies in accordance with the requirements of Good Laboratory Practice (GLP).

In Hydro, the options of establishing a specialist staff at the Hydro Research Center, Porsgrunn, or buying such competence externally, were discussed. From a financial point of view, such competence should be bought at the cheapest price available in order to avoid unnecessary expenses. Speaking in favor of internal competence, Krokan and other Hydro personnel claimed that Hydro would not be able to develop a therapeutic pharmaceutical product without at least some in-house competence. The Research Director supported this

[489] “Prosjektoppdrag: Finkjemikalier fra fiskeavfall. Budsjett 1988”
[490] See Chapter 12.6 for further details here.

argument and contributed to the establishment of the Department of Pre-Clinical and Clinical studies at the Hydro Research Center in Porsgrunn. This department was responsible for designing clinical and toxicology protocols, partly in cooperation with external firms.

Knut Heikås Dahl was hired as the head of the new department. He had previously been at the Department of Biotechnology. Heikås Dahl had a PhD in biochemistry and had worked for Nycomed, a Norwegian pharmaceutical company specializing in diagnostic tools. He took charge of the pre-clinical studies, and several researchers with relevant expertise were employed to see to the clinical studies. These researchers had all worked for Nycomed, and were well informed on the requirements of GCP. For capacity reasons, the Department of Pre-Clinical and Clinical Studies often co-operated with external Contract Research Organizations (CROs). At most, 8 to 10 people were involved in the department, including the staff in the new Lipid Laboratory. All together, they were responsible for establishing contact with external firms, monitor the studies, make sure the studies were properly reported, put things together, draw conclusions, and follow the progress of the project.

The first Phase 1 study was carried out in 1987 at an English contract laboratory. It was an important step in the clinical path. During the following years, several clinical studies were performed, relating to the treatment of conditions such as rheumatism, skin diseases, psoriasis, cardiovascular risk factors, and one particular kidney disease.[491] Børretzen, Krokan, and Heikås Dahl agreed that "*the more, the better*." Their argument was based on the knowledge that omega-3 fatty acids simultaneously affect several components of the biological system, and consequently also might influence several types of diseases. In addition, general interest for clinical studies was great, and several researchers worldwide contacted Hydro, requesting test material. Among those was a professor at the University Hospital of North Norway in Tromsø, who planned a blood pressure study on 100 patients. This professor knew Krokan and was well informed on his work on omega-3 fatty acids.

The blood pressure study, designed in cooperation by Krokan and the professor at the University Hospital, proved to be a good and important study. The study showed a beneficial efficacy of omega-3 on several cardiovascular risk factors, and was a decisive factor in the preparation for a product patent. It was the first large Phase 2 study, providing

[491] Here "everyday language"-terms, not the correct clinical terms, are used.

the basis for a subsequent Phase 3 study. Blood pressure studies had previously been carried out, but this was the largest double blind study[492] that was carried out so far. The demonstration of beneficial effects positively affected the general interest in the Omacor™ project. The “multiple investigative strategies” also proved to be economically beneficial. In the words of a project member:

> *…The pioneering part of it actually implied that, even if Hydro had spent a lot of money on this, we realize that if Omacor™ had been developed in one of the large companies we cooperate with, then we had spent hundreds of millions more – this is maybe one of the keys to success…*

However, some people argue that the “multiple strategies” had a number of less favorable effects, for instance related to the choice of indication. According to them, a sole emphasis on cardiovascular disease would have been a better strategy. Other people remark that the quality of the initial studies varied. As a project member remarked:

> *…Some times capsules were distributed without signing any formal deals. Actually, the fact that researchers were allowed to do what they wanted with this created problems later…*

Several conditions contributed to this situation. First, the initial studies were carried out in 1987, four years before an important EU directive came into force. Moreover, omega-3 products represented a kind of borderline medicine, since omega-3 products as nutrition supplements existed without particular requirements. As a consequence of this, there was initially some flexibility concerning documentation. One problematic implication concerned the quality of the initial studies in light of the requirements of Good Clinical Practice (GCP). Most of the performed studies, including the Tromsø study, were so-called investigator studies, i.e. they had not been monitored and carried out in accordance with GCP. As such, these studies could not be included in the required clinical file. Still, the investigator studies were useful as a background for subsequent studies, particularly for a documentation program that was started in the Department of Pre-Clinical and Clinical studies. Another problem concerned the efforts of tracing the distributed capsules, representing a great challenge for those responsible for preparing the clinical file.

[492] 1. A procedure in a clinical trial for issuing and administering treatment assignments by code number in order to keep study patients and all members of the clinic staff, especially those responsible for patient treatment and data collection, from knowing the assigned treatments.

Choice of Indication

For a multi-potent substance with a range of possible indications, choosing the "easiest" indication was seen as a smart initial strategy. In the words of a project member, "*When a therapeutic pharmaceutical has an initial approval for one indication, it is easier to obtain additional approvals later on".* In the case of Omacor™, *hypertriglyceridaemia* (increased level of triglycerides in the blood) was seen as an indication that could provide fast approval. Also, the market niche of this indication was small. Several Hydro people argued that when a product such as Omacor™ was registered for one treatment, it could be used for other purposes if the physician considered it to be the right treatment, so-called *off-label* prescription. For this reason, people in Hydro believed that the first product approval could give advantages through establishing market positions. There was, however, no unanimous agreement on the claimed benefits of off-label prescription. Some project members argued that such use is permitted in the US only. One of them said:

> *…The conclusion that the approval gives you permission to do almost everything was really not a good one because you are not allowed to do marketing for something else than the approved indication. I think the project would have been terminated at a much earlier date if one had been more critical at that time…*

Nevertheless, the documented efficacy of Omacor™ as a triglyceride-lowering substance was the decisive factor concerning the choice of indication. As a project member put it: "*Here you had a crisp and clear effect. There were no doubts about the efficacy*". Moreover, the *hypertriglyceridaemia* studies had been performed in accordance with GCP, meaning the results could be used. One also found that cardiovascular diseases represented a promising market potential for Omacor™. Thus, there were several factors pointing to *hypertriglyceridaemia* as the natural initial indication.

Yet, obtaining product approval for this indication proved to be a great challenge. Among other things, *hypertriglyceridaemia* was not officially accepted as a risk factor regarding cardiovascular disease, and definitions of *hypertriglyceridaemia* varied, as will be explained next.

The first Application for Product Marketing Authorization

The first application for product approval was filed in 1993, comprising 28 loose-leaf binders covering the pharmaceutical/chemical, pharmacology/toxicology, and clinical files. For applications within the EU, a so-called de-centralized multistage procedure was followed. According to this procedure, a so-called report country, acting on behalf of other EU countries, had to be found. Denmark was considered a natural choice in this case. As Sweden and Finland were not members of the EU at that time, national applications were filed in these countries. Both the Swedish and Finnish health authorities rejected the application, claiming that a clinical study, in which Omacor™ was compared to a particular reference substance, should have been performed. The reference substance in question was another triglyceride-lowering medicine previously introduced in the Swedish and Finnish markets, but (still) not in Norway. The Danish health authorities also rejected the application, arguing that *hypertriglyceridaemia* was not a real disease. According to them, there was no proof that a high level of triglycerides in the blood was a risk factor for cardiovascular disease. A project member commented:

> *…This has been a controversy for many years, and now there is more agreement that hypertriglyceridaemia is a real risk factor. At that time, it was not…*

In Norway, Omacor™ was approved for *severe hypertriglyceridaemia*, a different indication than the one applied for. The approval of this indication was surprising. As a project member put it:

> *…In the main documentation for the application, I think there were six people with severe hypertriglyceridaemia, and then Norwegian health authorities approved an indication that hardly existed in our documentation!...*

The difference between the indications is related to the concentration of triglycerides in the blood. In Europe, concentrations between 2.3 millimols per liter and 4.6 millimols per liter (mmol/l) are defined as (moderate) *hypertriglyceridaemia*, whereas concentrations between 4.6 millimols per liter and 10 millimols per liter are categorized as *severe hypertriglyceridaemia.*[493] In the United States, on the other hand, the requirements for *severe hypertriglyceridaemia* are concentrations between 5.6 millimols per liter and 10 millimols per liter.

The fact that "hypertriglyceridaemia" was subject to different definitions and categorizations made the application process particularly complex. Also, the fact that few Norwegians suffered from *severe hypertriglyceridaemia* implied that "*there was not any*

[493] "Omacor™. An introduction. A new edition for a refined treatment. Pronova a.s." 1999, p. 10

money in this indication," as a project member put it. Nevertheless, people in Pronova Biocare accepted the situation.

In the US, the Food and Drug Administration (FDA) approved the file, but made a request for patients. This was because no persons with a triglyceride level below 5.6 millimols per liter were defined as patients. According to the FDA, two clinical studies and a long-term monitoring study had to be conducted in order to get approval. Therefore, Pronova Biocare initiated such studies in the United States.

With Pharmacia as a co-operating partner since late 1993, people in Pronova Biocare decided to file a new application in the EU. Pronova Biocare now chose France as the new report country. This was because France was the main market for Pharmacia and because an omega-3 low-concentrate had been approved for *hypertriglyceridaemia* there. People in Pronova Biocare co-operated with Pharmacia's department for market approval, adjusting and improving the file. They filed an application in France, obtaining approval for *hypertriglyceridaemia*, the original indication. The application was then filed in all the EU countries resulting in objections. Reading the objections, the applicants realized that they had to exclude certain countries, because votes were taken and all countries had one vote. To avoid rejection, they kept the countries whose objections they assumed could be met with additional documentation. The applicants prepared replies and finally obtained approval.

However, the cooperation agreement with Pharmacia was annulled as a consequence of the merger of Pharmacia and Upjohn. Thus, when Pronova Biocare finally had obtained approvals in six[494] European countries, they had no partners. From another point of view, the approvals as such represented a basis for the project to survive.

At this point in time, Pronova Biocare decided to suspend the search for a new partner for the time being, since they were waiting for the results of a large study (the so-called GISSI-study) carried out by Italian researchers. Positive results would mean the value of the product was much higher, and would facilitate getting a new partner.

[494] *k85* had previously been approved in Italia

The GISSI Study

The GISSI study was a large Phase 3 study[495] aimed at finding out if treatment with Omacor™, or the combination of Omacor™ and vitamin E, had a beneficial effect for patients that had recently suffered from a heart infarction. The study was inspired by the results achieved by American researchers who had found that omega-3 fatty acids appeared to have a beneficial, stabilizing effect on so-called arrhythmias, that is, unstable rhythm of the heart, a main cause of sudden death related to heart infarction.

Pronova Biocare's Italian marketing partner had strong links to the so-called GISSI-group, an Italian research group involved in research on cardiovascular diseases. This research group was very eager to do this study, and the marketing partner agreed. Pronova Biocare, on the other hand, was initially skeptical to these plans. One of the employees remarked:

> *…We were dedicated to a lipid-lowering path and were skeptical about going for another indication at the time. We had evaluated the previous work and decided to do only this…*

People in Pronova Biocare and Hydro were also convinced that the study would fail because the Italian researchers planned to use a dosage of *one* gram only. In the words of a project member,*"According to the results of research on lipid- lowering effects, four capsules were required to get a reliable effect. So, when these people suggested one gram, we said "No way!"".* Pronova Biocare tried to get involved in the decision but their objections were rejected. Nevertheless, the results of the GISSI-study, finished in 1999, proved to be "fantastically encouraging." They demonstrated a 20 percent reduction in total deaths and 45 percent reduction in sudden deaths due to treatment with Omacor™. The results thrilled people in Hydro and Pronova Biocare. One of them remarked:

> *…We went to Italy, expecting to hear how beneficial vitamin E is. But vitamin E did not have an effect at all! The effect was caused by Omacor™! That's probably the most important thing that has happened to this project!...*

Thus, contrary to all previous expectations, the GISSI-study became the medical breakthrough for OMACOR™.[496] The study provided Pronova Biocare with the required documentation to establish Omacor™ in a special niche, and secondary prevention in post-

[495] A Phase 3 study are large long-term clinical studies involving a large number of people with the disease(s) or risk factors.
[496] The costs of the study were about NOK 50 million. The costs of a similar study in 2002 were thought to be at least NOK 150 million, maybe as much as NOK 500 million.

MI patients (patients who have had a myocardial infarction) became the major indication for the future. Applications for approval of this new indication were filed, resulting in approvals in Norway and five EU-countries in 2001.

12.2.3 The "Commercial" Challenge

Since marketing is very important for selling drugs, approval of indications is critical for the financial success of a drug. Still, obtaining marketing authorization for a therapeutic pharmaceutical is a necessary, but not sufficient condition for developing a commercially successful therapeutic pharmaceutical. Commercial success implies that manufacturers also have to complete the *"commercial challenge"* of transforming the approved therapeutic pharmaceutical into a commercially successful product. This challenge represents a set of interrelated factors (Ref. the green part of Figure 12.2.2): *Manufacturing facilities*, making commercial large-scale production possible; *patents*, providing exclusive rights to the product invention and control of its manufacture for a limited period; *partners*, who may collaborate and share the risk of development, provide financial support, market and distribute the product, etc.; a governmental *system of reimbursement,* implying a cheaper, more accessible drug for patients; and finally, favorable conditions regarding *market* and *competition*.

Patents

When the Omacor™ project was started, omega-3 fatty acids had already been the focus of research for more than fifty years, meaning the potential for taking out new patens was low. In addition, omega-3 research was a field of increasing interest contributing to an "explosion-like" increase in the number of papers and patents on EPA/DHA during the project period.[497] Thus, the work aimed at getting patent protection was a critical and difficult activity in the Omacor™ project. Despite the challenges involved, Hydro researchers succeeded in their efforts, managing to obtain several patents for omega-3 concentrates.

[497] Doing patent searches in the fall of 1984 and in May/June 1985, Breivik found 4 and 28 Japanese patents respectively (Source: "Finkjemikalier fra fiskeavfall. EPA, DHA og kolesterol i torskeensilasje" 1985-06-21). In the end of 1985, he reported that "new patents on EPA/DHA are reported approximately 3 times a month, particularly in Japan" and that "the number of publications in the area has become several hundreds" (Source: "Finkjemikalier fra fiskeavfall. Status ved utgangen av 1985.") In 2002, there were about 110-120 papers every month on omega-3. Thus, Hydro had certainly entered into a very active and hot topic of research.

The project manager Harald Breivik and two of his colleagues applied for an omega-3 patent at the end of 1985.[498] This patent was approved as a *process* patent protecting the process, but not the product per se. As a consequence, Hydro needed a product patent providing stronger protection. Based on promising results from the clinical "blood pressure study"[499] and process refinements, Harald Breivik, Bernt Børretzen, Knut Heikås Dahl, Hans Krokan, and a professor at the University Hospital of North Norway in Tromsø filed a product patent in 1988 ("the *k85* patent"). Getting the "*k85* patent" approved proved to be a real challenge, including the need for developing well-defined solutions concerning claims about the inventive step of the patent, long-term negotiations with American patent authorities, and a patent case in Germany.[500].

The inventors of the Hydro patent became aware of another product patent, the so-called Dyerberg patent, which might obstruct it. This patent included a pharmaceutical formulation in which at least 50 percent of the fatty acids was provided by EPA. As Børretzen explained:

> *…As a consequence, whatever happened, we could not introduce products where the concentration of EPA was more than 50 percent, meaning concentrations down to 47 percent as you always has some degree of uncertainty…*

The patent inventors developed a set of parallel strategies to deal with the problem. The Dyerberg patent included a pharmaceutical formulation in which the concentration of EPA was at least 50 percent of the fatty acids. For this reason, the Hydro researchers adjusted the specifications of EPA/DHA so that their formulation contained less than 50 percent EPA. Next, they worked out well-defined solutions concerning claims about the inventive step of the patents. The inventors also emphasized strong follow-up of patents from "country to country". Børretzen said:

> *…The way I see it, there are people at various patent offices who will comment the text. They are not experts in the field and make searches in their data bases to be able to say whether this is relevant or not. They ask us to tell how this is different, and then you have to give an explanation…*

As a consequence, the Hydro inventors often joined the people from Hydro's Patent office on their visits to foreign patent offices.

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[498] Ref. Development of Product and Production Process (Chapter 12.2.2).
[499] Ref. Pharmacology/Toxicology (Pre-Clinical) and Clinical Studies (Chapter12.2.2)
[500] In the following I give a brief overview of the particular challenges involved, postponing an in-depth description of these to Chapter 12.6.3.

In the US, the "*k85* patent" met considerable opposition. In addition, a new patent that was not yet public made the argumentation particularly difficult. Here statements made by Breivik's professional contacts became decisive for obtaining patent approval.

Finally, finding that the patent represented common knowledge existing at the date it was filed, the inventors realized that they had to "*kill the patent*," as Børretzen put it. The patent case was handled by Børretzen and people from the Hydro Patent Office. It turned out to out to be a challenging and long-lasting process, but Hydro finally won the case.

Partners

In 2002, the status regarding partners to market, sell, and distribute Omacor™ was promising. Through a variety of license and supply agreements, Pronova Biocare had obtained access to several European markets, Asia and the USA, and, due to the new approvals for secondary prevention in post-MI patients, the forecasts for a commercial breakthrough was stronger than ever before. Entering into partnerships with pharmaceutical companies had been a difficult task, though, including several setbacks.

The process of getting a partner started in 1987. This was seen as favorable from a learning perspective.[501] Gulbrandsen, the principal, and the Vice President of the Agriculture Business Unit had key positions in this process. In addition, Krokan and Helkås Dahl, the heads of the departments of Biotechnology and Pre-Clinical and Clinical Studies, respectively, took part in meetings with potential partners, providing information on the product, status of documentation, etc. The aim was to get potential partners involved in the further development and marketing of the product by offering a ticket to future investments and income. Several established pharmaceutical companies were approached, involving a lot of trips worldwide to sell the project.

The size of potential partners was an issue of debate. Some people spoke in favor of alliances with large pharmaceutical companies. Others found that medium size companies, "hungry" for a new product, might be an interesting alternative. During the first years, the former view dominated. Still, Hydro did not succeed in getting a large partner until the cooperation agreement with Pharmacia was signed in late 1993. The situation of having no external partner in the early stage has been considered as one of the main objections to the Omacor™ project. A project member said:

[501] Svendsen (1996)

> *…I think some people found the stage with no external partner difficult. According to a philosophy in Hydro, getting an external partner meant not only shared expenses, but an external sponsor for the project as well: You share not only the risk of investments, but also the risks of the idea, that is, the risk of an unsuccessful idea...*

As the partnership with Pharmacia proved to be unsuccessful, terminated within a relatively short time, the strategy of selecting large partners was regarded as a failure, considered to be too ambitious. Based on the accumulated experiences concerning partners, Pronova Biocare decided to approach local and regional partners. The cooperation with the Italian pharmaceutical company involved in the GISSI study is an example of this approach. According to the agreement between Hydro and the Italian partner, Hydro would supply *k85* and the company would encapsulate it and use their trademark on the product. The application for product approval in Italy, subject to less strict restrictions than those discussed above, was also taken care of by this company. Approval was obtained in 1991, followed by a successful market introduction.

By the end of 2001, Pronova Biocare was able to offer potential partners a complete commercial package, including documentation, patents, etc. presenting with a stronger basis for negotiation than in the early phases of the project. Having obtained product approvals in several countries was also seen as beneficial; the pharmaceutical companies could then market Omacor™ immediately in the countries where the product was approved. Moreover, the new indication regarding secondary prevention of post-MI was a much more favorable indication than *hypertriglyceridaemia*. In the words of a Pronova Biocare employee, "*Selling this [indication] is easier than a risk factor without a firm basis, because now we have the figures from the GISSI-study to support our claims.*"
Project members also point out that the ability to offer lower concentrates of omega-3 as well, gave Hydro/Pronova Biocare a favorable position concerning partners.

The partnership side to the Omacor™ project also included several situations in which the potential partner lost interest in the project. The case of Pharmacia was caused by conditions beyond the control of Hydro/Pronova Biocare. Another case highlights the importance of enthusiastic supporters. A Pronova Biocare employee told:

> *…We had a promising cooperation with a pharmaceutical company in the Far East. And there was an enthusiast in Singapore, and we planned to apply for approvals in a couple of countries. Then this enthusiast left the company. We had great expectations for this area, and then the situation suddenly changed completely!*

> *Now sales there are very low. And this demonstrates that having a "god-father" in such large companies, is very important…*

The image problems omega-3 products suffered in the late 1980s due to poor products and misleading marketing represented another obstacle. Because of this situation, major US operators at this time were reserved, waiting before making their next move.[502] Finally, the following example illustrates how circumstances related to the issues of patents and indications affected a potential partner's interest in the project. One of the project members recounted:

> *…One of the largest pharmaceutical companies was interested in cooperating with us. But then we had this patent case. I don't know if it ruined the cooperation, but the patent had a considerable influence on our relations with the company…However, is was not just the patent in this case: At this time, the effect of EPA and omega-3 on cholesterol received the greatest attention. People couldn't care less about all the other effects…* ***What mattered was cholesterol-lowering effects****, representing a market factor because doctors could easily measure the level of cholesterol. Consequently, access to the market would be easy. Cholesterol lowering medicines… came on market in the late 1980s/early 1990s, proving to be a big product. At that time there were no cholesterol-lowering therapeutic pharmaceuticals available. In the case of the Tromsø study, this company was expecting that Omacor™ should show a beneficial effect on cholesterol.* ***Thus, in addition to the patent, the report documenting the effect of Omacor™ on a range of risk factors, but not on cholesterol,[503] was critical, and meant that the deal with this company did not go through****. That was disappointing, because the forecasts for this cooperation were very promising…*(emphasis is mine)

The Market

Normal body functions depend on the body getting a regular supply of omega–3 fatty acids through a healthy, balanced diet including fatty fish.[504] As modern food habits had resulted in too low an intake of these acids, the interest for EPA/DHA as a nutritional supplement increased during the 1980s. The decreasing intake of fatty acids in the population had been linked to many diseases, particularly cardiovascular disease – the main cause of death in the Western world.[505] As such, the development of a therapeutic pharmaceutical based on a high concentration of omega-3 was seen as a promising project. Still, the market for therapeutic pharmaceuticals treating cardiovascular diseases was enormous, implying that entering into the cardiovascular market with Omacor™ was difficult. In addition, the bad

[502] Svendsen (1996)
[503] The total level of cholesterol
[504] Brochure Pronova Biocare, The World's leading company of Omega-3 fatty acids.
[505] Omega-3 magasinet. Informasjon om Omega-3 fettsyrer, Pronova Biocare a.s, 1994

image omega-3 products had in the late 1980s represented an additional challenge for the developers of Omacor™. The idea of a high-concentrate omega-3 therapeutic pharmaceutical was also subject to criticism. According to project members, several Norwegian physicians objected to the claimed need for an omega-3 drug, arguing that people would be better off eating more fatty fish or taking cod-liver oil. The applicability of the multipurpose effects of Omacor™ was also questioned. "*Omacor™ was seen as a "snake oil"- an oil which is able to cure everything - by people who never realized the biochemical mechanism causing the number of simultaneous effects*", a project member commented. Yet, people in Hydro/Pronova Biocare emphasize that it was not the variety of indications, but the *strength* (and perceived attractiveness) of indications, as well as the size of potential target groups, that was the most important element in the Omacor™ project. Moreover, the many different definitions of "hypertriglyceridaemia" and the controversy over its status as a cardiovascular risk factor, limited the potential of Omacor™ in the broad market of lipid-lowering drugs. The great variety of products within this market was also a problem. A project member commented:

> *…The market for lipid lowering drugs is very broad. Omacor™ does not reduce cholesterol in the same way as the cholesterol lowering drugs, but have several other effects being equally interesting. However, because this is a very "intellectual" message, it's hard to establish a market. Physicians prefer simple messages…Saying that cholesterol is a risk factor, is easier. Triglycerides are far more difficult. That's no established risk factor. However, those who are informed in this area know that triglycerides are the really risky thing…*

On the other hand, the "big" indication concerning secondary prevention in post-MI patients implied a much larger market potential. In 2001, the target group in the US and European markets comprised approximately 11 million patients.[506] Consequently, people in Pronova Biocare considered the market potential in these markets as highly promising.

The Competitive Position of Omacor™

Compared to other omega-3 products, OMACOR™ has all along been the leading product in terms of quality and concentration. In 2001, the product had no direct competitor in the market.[507] The comprehensive documentation on Omacor™ was unique. No other omega-3

[506] "Dagens Næringsliv" 2001-12-11
[507] Ibid.

product had passed such a rigorous testing program to meet international documentation requirements for pharmaceutical products as Omacor™.[508]

Several people in Hydro/Pronova Biocare considered its high concentration to be one of the main competitive advantages Omacor™ has. A high-concentrate means that the number of capsules taken can be kept at a minimum, an important factor in making people follow up the treatment over time. The purity of Omacor™ is also an advantage compared to lower concentrates. Furthermore, the product's "surprisingly high" efficacy compared to lower concentrates of omega-3 fatty acids, and the fact that no serious side effects had been reported in treatments with Omacor™, were recognized as other distinctive advantages of Omacor™. During the late 1990s, however, other cardiovascular medicines without negative side effects were also developed. As such, Omacor™ faced keen competition concerning this advantage. In this connection, the point that Omacor™, as opposed to these competing products, is based on a natural raw material is not necessarily an advantage, because fish oil is an expensive raw material compared to synthetic chemical substances.

Nevertheless, Omacor™ was not expected to compete with specialized products aimed at specific acute treatments. In accordance with the approval of the secondary prevention in post-MI patients, Omacor™ was to be used as an additional treatment to the standard recommended treatment package post-MI patients undergo. At the same time, referring to the results of the GISSI-study, people in Pronova Biocare pointed out that Omacor™ produced unique effects, distinguishing the product from other "heart medicines": Adding Omacor™ to the standard treatment package did not only demonstrate a reduction of total deaths; it also demonstrated a 45 percent reduction of sudden death. No other heart medicines had documented similar effects.

System of Reimbursement

The situation concerning governmental reimbursement for Omacor™ has changed over time. In Norway, the health authorities refused reimbursement for the indication of *hypertriglyceridaemia*, claiming that this indication was not a risk factor, and that treatment with Omacor™ was unnecessary. In 2001, the application for reimbursement regarding secondary prevention of Post-MI was pending approval. Pronova Bioacare expected it to be approved.[509] However, people in Hydro/Pronova Biocare commented that Norwegian

[508] "OMACOR. And introduction. A new edition for a refined treatment." Published by OCC, London 1999, on behalf of Pronova Biocare
[509] According to http://www.legemiddelsiden.no, 2006-05-11, Omacor™ has now become part of the reimbursement system in Norway.

health authorities "have a rigid attitude towards new therapeutic pharmaceuticals". One of them put it this way:

> *...Expenses are cut. It is a fight for money. The national economy, not the individual patient, is taken into account. The number of lives that may be saved is not considered. This is a therapeutic pharmaceutical developed in Norway. They should think protectionist. This is a political issue where we have to influence politicians from locations where we have our plants. That's a terrible system!...*

In Italy, Omacor™ was reimbursed, boosting sales. In 1993, however, the system of national reimbursement was terminated due to fraud and corruption, and the Italian market collapsed. This was a critical event, causing discussions on terminating the project. As a project member said:

> *…The termination of the Italian reimbursement system weakened the possibilities for making contacts with companies in other European countries; it is always useful to have some point of reference concerning approvals, markets and contacts…*

In 2001, after the GISSI-study, the situation improved, though. Omacor™ was re-launched in the Italian market and obtained reimbursement. In France, reimbursement of Omacor™ was also subject to difficulties. A short time after Omacor™ had obtained reimbursement for *hypertriglyceridaemia* France decided to cut public resources, among other things, reimbursement for therapeutic pharmaceuticals such as Omacor™. As a consequence, sales plummeted. Based on the obtained approvals for secondary prevention in post-MI patients in 2001, people in Pronova Biocare considered the forecasts for obtaining reimbursement in France and several other European countries a number of countries as far better than before. The situation represented promising forecasts for a commercial breakthrough.

12.2.4 A Supplementary Presentation of the "Pharmaceutical" and "Commercial" Challenges in Light of Competence

As discussed in Chapter 9.3, insufficient competence in the Omacor™ project made the path towards a commercial success unnecessary long. This finding is essential in light of my question of which types and compositions of competence are needed to succeed with innovation (Ref. Chapter 12.5). Struggling to find a proper way of highlighting this issue in the foregoing systems analysis I here provide a supplementary presentation of the "pharmaceutical" and "commercial" challenges in light of competence.

Most project members point out that neglect of the importance of involving necessary competence retarded the progress of the project. One project member argued:

> *…Omacor™ would have had a more rapid development if one had engaged people who were really experts in this field; if we had had a professional organization that really mastered the business, we would have reached our goals a long time ago...*

Arguing in line with the former, another project member said:

> *…For a long time competence has been insufficient. And that has probably influenced the actual progress of the project. It has taken too long time… Here we needed specialist competence in* ***so*** *many areas. You should not think that you are competent to do everything just because Hydro is the largest Norwegian industrial company. You have to assess where you are before you begin: What kind of competence do we need? That's what they did in oil & gas. Here they employed people with a specialist competence and offered them high salaries in order to develop the Hydro oil business. They should have done the same thing within pharmacy, too...*

Describing the situation, a third project member commented:

> *…There were lots of bright, highly skilled, intelligent people, but that is of little help when the whole organization suffers from the same condition: A lack of experience in developing a therapeutic pharmaceutical. In this field you need a lot of specialist competence, and such knowledge is not easily found in Norway…*

In particular, project members claim the project suffered from insufficient marketing expertise, lack of expertise regarding pharmaceutical business planning, and inadequate knowledge of the pharmaceutical market, that is, competence of special importance for dealing with the "commercial" challenge. A project member said:

> *…One did not care about the situation of the customers. For instance, how many capsules may a potential patient be willing to take? What competition will the product meet in the market? Which segment should be chosen? – The cardiovascular area is a gigantic area with therapeutic pharmaceuticals for any condition. The big pharmaceutical companies have had cardiovascular disease as a priority for more than 30 years. They are well established in the market and have spent lots of money to establish their products. Thus, this was not an easy task, but one did not care about that…*

Similarly, another project member commented:

> *…There was a lack of knowledge of the pharmaceutical market and we should have had a critical assessment of the market potential.* ***Reading statistics is not enough. You have to know something more!****...*(emphasis is mine)

According to project members, a professional marketing group would have provided a sound clinical plan including a clear strategy, a proper choice of indication from the very beginning, and thus an orderly course. Some also remark that professionals probably would have initiated large clinical studies at an earlier point of time. As one of the project members explained:

> *…In this case, waiting so long before doing the clinical studies that may open the way to the large markets was a blunder, One was not sufficiently mature within this trade to see what had to be done and take the risk: OK, maybe this will cost NOK 30-40 million and the result may be negative, but at the same time you must be willing to take that risk…*

Furthermore, project members indicate that potential partners may have disclosed the lack of trade knowledge, making it more difficult to establishing partnerships. Some also suggest that the status of Hydro sometimes appeared to be considered a qualification in it self, opening doors in favor of the company.

Several project members link the competence shortage to Hydro's career policy favoring internal appointments. In the words of a project member:

> *…According to the Hydro philosophy, a manager is able to manage anywhere. They move managers around. You actually don't need professional knowledge within the area you are supposed to manage. I regarded – and still regard - this as a strange policy…*

Similarly, another one commented:

> *…They were skeptical to engaging professional people from other areas, even in areas of which one had no previous experience. They should use their own. And I think that is the reason why so many mistakes were made…*

On the other hand, a couple of project members indicate that lack of necessary trade competence may be an important reason for the very existence of the Omacor™ project. In the words of a project member:

> *…If Hydro had been an experienced pharmaceutical company, this project would hardly have become a reality, because it is so difficult to estimate correctly the profit and market potential of such a product…*

Similarly, another claimed: "*If Hydro really knew what they entered into, or acquired this knowledge through others, this project would never have been continued*."

12.3 Which Activities by Which Actors/Organizations Are Important to Succeed with Innovation?

The systems analysis of the Omacor™ project provides a solid illustration of innovation as a social, collective achievement. It shows that the project was a collective open-ended activity composed of interrelated sub-activities performed by a large number of people. All together, the actors collectively constituted the ensemble of specialists influencing the creation and implementation of a patented approved drug based on omega-3 fatty acids from fish oil.

Chapter 12.2 gave a comprehensive presentation of which activities by which actors/organizations were important to succeed with the Omacor™ project. To summarize, the systems analysis of the Omacor™ project shows that innovation success depended on solving two interrelated open-ended challenges, the "pharmaceutical" and "commercial" challenges.

The "pharmaceutical challenge", representing the set of interrelated factors needed to obtain marketing authorization for Omacor™, involved several interlinked activities that each included a multitude of sub-activities. The main activities pertaining to the "pharmaceutical challenge" was the *development of a product and production process*, *pre-clinical studies*, and *clinical studies*.

The *development of an omega-3 medicine and the production process* for it in accordance with GMP comprised a wide variety of sub-tasks, for instance: *exploration of commercial interesting components in the "problematic" fish waste*, *investigation of relevant methods and technology for analysis*, *fundamental discussions regarding types of raw material and omega-3 products*, *scaling-up efforts*, *trial production*, *work aimed at getting access to suitable process components (non-coated urea)*, *efforts directed at finding a proper use for by-products occurring in the process (the "UFF")*, *securing product* *stability and reliability, chemical analysis, and the comprehensive work aimed at documenting and monitoring the product and process in accordance with GMP.*

In turn, these sub-activities represented comprehensive tasks in themselves. *Chemical analysis*, for example, included both the challenging task of making proper analysis of the unusually complex raw material and the extraordinary efforts directed at the development and definition of standard international methods of analysis for omega-3 concentrates. The case concerning official analysis methods is particularly noteworthy. It indicates that even though specific organizations had the decisive authority regarding institutional rules, Hydro's efforts directed at influencing the creation of and change in relevant institutions were important to succeed with innovation. The analysis case also shows that work aimed at establishing customer certainty of product quality (trust) under conditions of high-quality uncertainty was important (Ref. Van de Ven et al., 1999). As such, it suggests that the development of strategies to influence actors and institutions affecting the innovation process was an important activity in the Omacor™ project.

Moreover, the *pre-clinical and clinical studies* covered a large range of activities such as the accomplishment of *different types of studies* and *documentation in accordance with GLP and GCP*. In addition, *choice of indication, examination of the files in question and the writing of expert reports*, and finally, *the assessment of the overall documentation necessary for filing the application for approval*, were major activities needed to obtain marketing authorization.

In sum, the activities pertaining to the "pharmaceutical challenge" involved a great number of actors across disciplinary and organizational borders, for instance: an interdisciplinary group of researchers at the Hydro Research Center in Porsgrunn, Hydro managers, trial production plants, suppliers of raw material, encapsulation firms, pharmaceutical companies, laboratories world-wide, experts on chemical analysis of omega-3 fatty acids and marine oils, Contract Research Organizations, hospitals, and national and supranational health authorities.[510]

Similar to the "pharmaceutical challenge", the "commercial challenge" in the Omacor™ project involved many composite activities such as *work aimed at getting proper production facilities*, *efforts directed at obtaining patent protection*, *work aimed at getting pharmaceutical companies as partners*, *investigation of market issues and the competitive situation for relevant indications*, *work aimed at creating a competitive advantage for*

[510] Since Chapter 12.2 provides a clear presentation of which actors performed which activities, I here briefly list some key actors to illustrate the great variety and number of actors involved.

Omacor™, and *efforts concerning the obtainment of reimbursement*. These activities were performed by a great variety of actors such as the researchers inventing the omega-3 patents, Hydro managers, Hydro's patent office, external patent offices pharmaceutical companies, fish oil companies, and Norwegian as well as foreign health authorities.[511]

Thus, the systems analysis of activities and actors in the Omacor™ project shows that the project represented a social, collective activity composed of a large number of people. The overall achievement, assessments, discussions, negotiations, decisions, and involvement of these in the multitude of sub-activities influenced the possibility for developing a commercially successful drug. Still, a proper discussion of which activities of which actors were important to succeed requires further attention to the *relations* between the activities/actors in the Omacor™ project.

Chapter 12.2 illustrates that the various project activities and sub-activities in the Omacor™ project were complementary; if one critical component was lacking, or failed to develop, the progress of the entire innovation system was blocked or slowed down (Ref. Fagerberg, 2005). For instance, the development of sufficient amounts of *k85* was a prerequisite for doing the required pre-clinical and clinical studies. At the same time, the need for large quantities of the test substance, combined with strict deadlines for release, restricted the possibility of process improvements aimed at cost reduction.

Still, the most striking finding regarding complementarities is that *the procurement of marketing authorization was necessary, but not sufficient for transforming the drug into a commercial success*. In particular, the complex interrelationships between components pertaining to the ”commercial” challenge is noteworthy. For example, the initial marketing authorization for Omacor™ in Norway was practically useless, because the target group in the market included six patients only. In contrast, the approval for secondary prevention in post-MI patients in the US and several European countries in 2001 implied a much larger market potential (approx. 11 million patients). Thus, the Omacor™ projects shows that obtainment of approvals for indications allowing for the broadest possible use of the drug in order to maximize the financial return on their investment in developing the drug, is indeed important. At the same time, the project calls attention to that approval for favorable indications in terms of market potential are of little value unless the therapeutic

[511] However, since my primary focus is on *activities* and actors involved in these, and since I have little data on the actions of competitors, I pay little attention to potential customers and competitors here.

pharmaceutical obtains *reimbursement* in the relevant markets. For instance, when the Italian reimbursement system was terminated in 1993, the Italian market for Omacor™ collapsed. Similarly, sales decreased in France when the reimbursement program for drugs like Omacor™ was terminated. These cases also show that decisions regarding reimbursement are beyond the control of the drug manufacturer. Moreover, the French example suggests that the perceived importance of an indication plays a major role in assessments regarding reimbursement. The fact that Norwegian health authorities refused reimbursement for *hypertriglyceridaemia*, claiming that this indication was not a risk factor exemplifies this. Evidently, *hypertriglyceridaemia* was a weak indication compared to the secondary prevention in post-MI patients, not least because the status of it as a cardiovascular risk factor was subject to controversy. Therefore, based on the obtained approvals for secondary prevention in post-MI patients in 2001, the forecasts for obtaining reimbursement in Norway, Italy, France, and several other European countries appeared to be far better than before. Still, the Omacor™ project highlights that approvals, reimbursement, and a promising market potential, are of little value if the manufacturers have no *patent* rights. Also, *this* series of factors will not result in commercial success if a manufacturer with no in-house marketing department has no *partners* to help distribute and market the product.

The chances of entering into a successful *partnership* depend largely on the status regarding the other factors necessary to develop a commercially successful drug. For instance, the Omacor™ project shows that the perceived strength and attractiveness of an *indication* may play a major role, as seen in the case with the potential partner making a request for cholesterol-lowering drugs only. Similarly, it illustrates that uncertainty surrounding *patent rights*, as reflected in the potential partner's attention to the patent case, may affect the outcome of partnership negotiations. The project also indicates that Hydro's shortage of trade knowledge in pharmaceutical product development was a possible obstacle to establishing partnerships.

Furthermore, the Omacor™ project illustrates that the success regarding establishing partnerships may be affected by external conditions over which the manufacturers have no control. For instance, the merger of Pharmacia and Upjohn brought the cooperation with Pharmacia to an end, meaning Pronova Biocare suddenly had no partners when finally having obtained approvals in six European countries. Similarly, the promising partnership with an Eastern pharmaceutical company was ended (or at least strongly negatively affected) when a local champion left the company.

Finally, the Omacor™ project calls attention to that the successful achievement of critical factors is a strong advantage. For instance, when Pronova Biocare in late 2001 was able to offer potential partners a complete commercial package including approval for a strong indication with respect to market potential, forecasts for reimbursement in several countries, patents, a favorable competitive situation, etc., the forecasts for getting partners was much stronger.

Accordingly, the Omacor™ project shows that the development of a commercially successful therapeutic pharmaceutical depends on several *interdependent* activities including the comprehensive work aimed at procuring marketing authorization, reimbursement, patents, manufacturing facilities, partners, and conditions regarding market and competition. The actors in the system of innovation were thus highly interdependent, meaning the achievement of specific activities performed by specific actors in one part of the system depended largely on actors and activities in other parts of the system. As such, the successful achievement of *one* specific open-ended innovation activity such as the procurement of patents *increased the probability for* overall success only. Clearly, commercial success would not be possible without patents. At the same time, patents were no guarantee of success of the Omacor™ project as a whole. Thus, the analysis of the Omacor™ project by means of the SI approach shows that innovation is a social, collective activity of which the state of the activities and their relationships determine innovation success.

To summarize, my systems analysis of the Omacor™ project provides a comprehensive illustration of the activities that were necessary to succeed with developing a commercially successful drug based on omega-3 fatty acids from fish oil. As such, it provides context-specific knowledge of the overall collective activity needed to develop a commercial success in the field of pharmaceutical product development, but no general answer to the question of which activities of which actors/organizations are important to succeed with innovation.

12.4 Which Institutional Rules Influence the Activities of Actors/Organizations in Carrying Out Activities in Innovation Processes?

Institutions are sets of common habits, norms, and routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups, and organizations (Ref. Edquist, 1997; 2005).

The systems analysis of the Omacor™ project calls attention to important institutions that influenced the performance of activities in the Omacor™ project. As such, it provides context-specific, but no general knowledge of which institutions influence actors/organizations in carrying out activities in innovation projects.

The dominant role of institutions regulating pharmaceutical product development is a salient characteristic of the project as an innovation system. The Omacor™ project shows that the development of new drugs is subject to strict guidelines (GMP, GLP, GCP) imposed by national or supranational regulatory authorities. These demands make drug development a complex, time-consuming process. Also, the project shows that important institutions pertaining to the pharmaceutical product development may differ among regions and countries, causing delays and duplication of work for the pharmaceutical manufacturers in question. For instance, Sweden and Finland rejected the initial application for *hypertriglyceridaemia* because the regulatory authorities in these countries demanded a specific comparative study that Hydro/Pronova Biocare had not performed. Similarly, off-label prescriptions were allowed in the US, but not in Europe.

Furthermore, the Omacor™ project demonstrates that the definition of relevant diseases may differ considerably among countries. For example, the status of *hypertriglyceridaemia* as a cardiovascular risk was subject to great controversy. In addition, the regulatory authorities in the US and the EU defined *hypertriglyceridaemia* and *severe hypertriglyceridaemia* differently, adding ambiguity to the issue of target groups. These differences, in turn, influenced assessments concerning *reimbursement* of Omacor™. In Norway, for instance, the health authorities refused reimbursement for the indication of *hypertriglyceridaemia*, claiming that this indication was no risk factor and that treatment with Omacor™ thus was unnecessary.[512]

Along with the regulations concerning the quality, safety and efficacy of new drugs, *patent laws* played a considerable role in the Omacor™ project. The general requirement of

[512] It is also evident that national health budgets influence the actual formulation of third-party reimbursement systems.

novelty implied a great challenge for the Hydro inventors, not least because of the great number of existing patents describing effects of omega-3 on cardiovascular diseases.[513] In addition, the objection raised by US patent authorities points out that patent claims may be subject to *interpretative flexibility* (Ref. Pinch and Bijker, 1987).

Finally, the work surrounding analysis methods calls attention to *context-specific institutions* relevant for the Omacor™ project, but not for pharmaceutical product development in general. The project shows that lack of official methods for analyzing omega-3 fatty acids, especially high-concentrates, made the analysis part of the project particularly demanding. Still, the most striking finding here is that the difficult situation inspired Hydro researchers to contribute to the development and definition of institutions in the sense of standard international analysis methods for omega-3 concentrates.

Thus, to summarize, the systems analysis of the Omacor™ project calls attention to major institutions directing the overall innovation activity in this project. In addition, it demonstrates that different national/supranational institutions, as well as the interpretative flexibility of rules, added considerable difficulties for Hydro/Pronova Biocare. It also shows that institutions or more specifically, *lack* of standard rules, triggered activities aimed at creating or changing institutions.

12.5 Which Types and Compositions of Competence Are Important to Succeed with Innovation?

The systems analysis of actors, activities, and institutions in the Omacor™ project shows that innovation is a collective, open-ended activity requiring the involvement of a great many specialists who collectively represent a large variety of expertise. At the same time, it indicates that the answer to the question *What types and compositions of competence are important to succeed with innovation*? is context-dependent, relying of the main function of the innovation system in question. As such, the systems analysis of the Omacor™ project sheds light on the specific types and composition of competence needed to process omega-3 fatty acids in fish oil into a drug ready for the customer.

My study of the Omacor™ project illustrates that the achievement of the system's main function depended on solving two interrelated open-ended challenges, the "pharmaceutical"

[513] The fact that patent laws may differ between countries added further complexity. This is illustrated through the outline of the patent case Chapter 12.6.3.

and “commercial” challenges respectively. Each of these challenges included a set of interrelated activities and sub-activities whose completion presupposed specific expertise. Among other things, the documentation requirements for therapeutic pharmaceuticals made strict demands on expertise regarding the “pharmaceutical challenge”. For instance, the Hydro researchers had to acquire knowledge of how to analyze omega-3 concentrates and learn how to perform the procedures for monitoring the product and production process in accordance with GMP. Without this expertise, the procurement of marketing authorization would not have been possible. Similarly, the Omacor™ project suggests that shortage of relevant expertise such as insufficient marketing expertise, lack of expertise regarding pharmaceutical business planning, and inadequate knowledge of the pharmaceutical market retarded the progress of the project. It made the path towards commercial success unnecessary long. Accordingly, the Omacor™ project underscores that innovation success implies the involvement of relevant competence in *all parts* of the system and that the neglect of this need blocks or slows down the progress of the entire innovation effort. This finding points up that the expertise needed to deal with the “commercial challenge”, often labeled “commercialization” or ”implementation”, is no less important than competence required to create and develop new products or processes. As such, it also indicates that creativity is needed in all parts of the innovation system; innovation is not a matter of heuristic “technological” tasks and algorithmic “commercial” tasks, as several existing innovation models seemingly suggest.

Thus, the systems analysis of the Omacor™ project shows that the achievement of the innovation activities as a whole requires that the actors/organizations involved *collectively* possess the types and composition of competence demanded by the system’s main function. If critical competence needed to successfully accomplish activities in one or more parts of the system is insufficient, the development of the entire system will suffer. The systems analysis thus clearly illustrates the importance of *requisite variety* (Ref. Nonaka and Takeuchi, 1995; Morgan, 1997). Requisite variety here means sufficient diversity of competence to deal with the complex, composite challenges posed by the main function of an innovation system; the types and composition of competence must match the complexity of the system.

Furthermore, my analysis of the Omacor™ project suggests that the successful achievement of specific project activities often require *context-relevant skills*[514] in the sense

[514] Context-relevant skills are relevant knowledge of the problem context and technical skills required.

of *relevant knowledge* of *other* activities or factors influencing innovation. Among other things, several considerations regarding the “pharmaceutical” challenge concerned “commercial” issues, for instance the question of production costs and market potential for mixed versus pure omega-3 concentrates. Similarly, the Hydro researchers’ strong attention to methods of analysis was directed by their knowledge of omega-3 research as well as their acquaintance with current market trends of omega-3 products. As seen, careful attention to analyzing methods was vital for the procurement of marketing authorization (the “pharmaceutical challenge”). Yet, it was as least as important for succeeding with the “commercial” challenge: Clearly, the strong emphasis on proper methods of analysis of omega-3 concentrates was necessary for giving Hydro a distinguished competitive advantage in the market currently associated with non-serious actors and low-quality products. Accordingly, the Omacor™ project illustrates that expertise in the sense of *domain-relevant skills* often is insufficient: The successful accomplishment of tasks pertaining to specific activities or challenges in a system of innovation generally calls for context-relevant skills in terms of relevant systems specific knowledge. Therefore, the achievement of specific project tasks implies that the experts involved have sufficient *task-relevant skills*, i.e. both domain-relevant skills and context-relevant skills (Ref. Chapter 8). This finding has important implications.

First, the finding concerning the significance of relevant systems specific knowledge points up that terms such as “pharmaceutical” and “commercial” expertise should not be considered as totally distinct types of competence. The terms represent narrow categories representing partly overlapping forms of competence.

Second, the finding emphasizes that participants in innovation project should recognize the significance of *context-relevant skills*. In particular, this applies to managers of innovation projects. More specifically, the finding in question suggests that innovation managers should have *knowledge of the business (trade)* in terms of knowledge of the determinants of specific innovations. For instance, managers of projects aimed at developing a therapeutic pharmaceutical should be familiar with the knowledge embedded in the systems model of pharmaceutical development (Ref. Figure 12.1). This knowledge demand forms a contrast to principles of the so-called *Kenning-tradition* that has played a prominent role in Norwegian leadership development (Kalleberg, 1991). As opposed to Kenning’s insistence on universal managerial principles and his claim that managers can lead *any* business irrespective of their professional background (ibid.), the Omacor™ project indicates that context-relevant skills in the sense of business (trade) knowledge is a significant managerial quality. Apparently, Hydro's management philosophy, at least the emphasis on recruiting managers internally, was inspired by the Kenning-tradition.

Commenting on the observation that several project members questioned the appropriateness of Hydro's carrier policy, a Hydro manager argued that most Hydro managers, having learned the ropes in the company, generally have solid knowledge of the business they are heading. Still, my data suggests that the strong emphasis on internal recruitment in the Omacor™ project reflects insufficient awareness of the importance of context-relevant skills in terms of relevant business knowledge. One explanation for this inadequacy may be that Hydro managers heading business areas traditional for the company easily pick up necessary business knowledge from in-house managers already possessing task-relevant skills. As such, the significance of context-relevant skills is not explicitly reflected upon, implying underestimation of the need for such expertise when entering into new business areas. Thus, I conclude that awareness of *context-relevant skills* in the sense of business or trade knowledge is necessary to succeed with innovation. Individual domain-relevant skills and/or high levels of managerial skills are not sufficient.

Still, it is worth recalling the finding that a couple of project members suggested that the lack of, or at least the insufficient business knowledge contributed to the very initiation and completion of the Omacor™ project. Accordingly, even though I believe that context-relevant knowledge is important, it is evident that the beneficial effects of Hydro's "blissful ignorance" concerning the real difficulties of pharmaceutical product development, or new businesses in general, cannot be ignored.

To summarize, the systems analysis of the Omacor™ project shows that innovation is a collective open-ended activity implying the involvement of a great many specialists who collectively represent a large variety of expertise. The types and compositions of competence needed to succeed with innovation are context-specific, depending on the main function of the innovation system in question. *To ensure requisite variety of expertise, the overall competence possessed by involved actors/organizations must match the complexity of the innovation system*. This finding reflects two essential points: First, innovation success implies the involvement of relevant competence in *all parts* of the system. Relevant competence means *task-relevant skills* covering domain-relevant skills and context-relevant skills in terms of relevant systems specific knowledge. In this connection, business or trade knowledge appears as a vital component of managerial competence. Second, the expertise needed to deal with the "commercial challenge", often labelled "commercialization" or "implementation", is no less important than competence required to create and develop new products or processes. As such, my study also indicates that creativity is needed in all parts of the innovation system; innovation is not a matter of heuristic “technological” tasks and algorithmic “commercial” tasks, as several existing innovation models seemingly suggest (Ref. Chapter 4).

12.6 How and Why Do People Use and Create Networks in Innovation Projects?

12.6.1 Introduction

In this chapter I shed light on networks found in the Omacor™ project, the PROSMAT “Die Life” project, and the PROSMAT “Bearing Channel” project because these projects provide the most prominent examples of how various networks influence collective creativity. Chapter 12.6.2 presents relevant networks of actors and organizations in the three case projects referred to, while Chapter 12.6.3 focuses specifically on *strategic alliances* forged to support project members’ interests and points of view regarding the new technology (Ref. Latour, 1987). In the latter chapter I highlight strategic alliances in the Omacor™ project only since this project gives the most pronounced illustration of such heterogeneous networks.

12.6.2 A presentation of Networks of Actors and Organizations

The Omacor™ Project

The actors involved in the Omacor™ project represented a complex cross-disciplinary, cross-departmental, and inter-organizational network. The collaboration across traditional borders was critical for success. In the words of a project member:

> *…We managed to compose a project team consisting of people with different competence and were able to benefit from it. We managed to get this interaction across professional areas and limits. I think we would not have succeeded if it weren’t for that…*

Figure 12.6.1 gives a broad illustration of this network.[515] The inner circle shows the cross-disciplinary, cross-departmental network of researchers at the Hydro Research Center, Porsgrunn. The outer circle covers other Hydro units, including companies acquired by

[515] The figure should be read as an illustrative, broad example of individuals/organizations involved in the Omacor™ project in the period between 1987 and 1989. Similarly, the other figures presented later should also be regarded as broad illustrations.

Hydro during the project period, while the rest of the figure represents external actors/organizations.

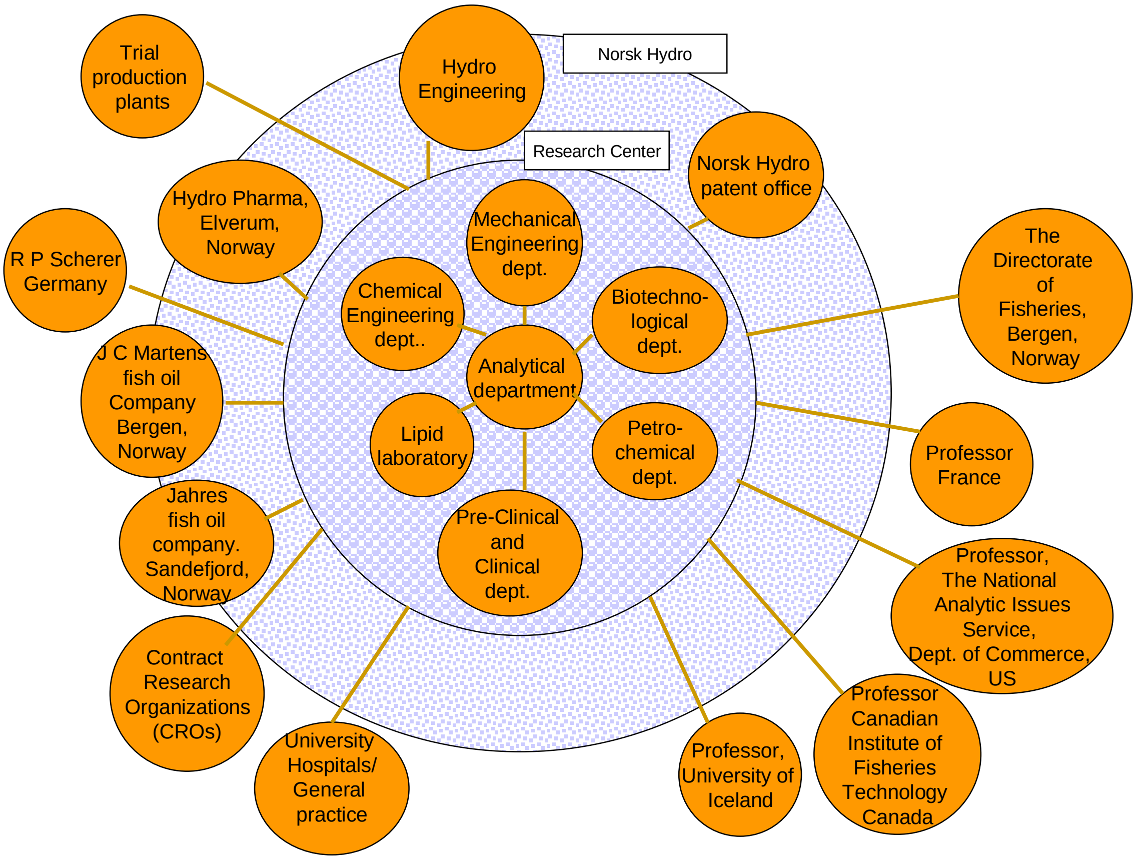

Figure 12.6.1 A Network Illustration of Actors and Organizations in the Omacor™ Project

Harald Breivik, the project manager responsible for preparing the chemical/pharmaceutical file, and some of his colleagues in the *Analytical department* carried out the initial research activities. The first patent, as well as the later omega-3 patents, was prepared in close collaboration with people at *Hydro's patent office*. The Hydro patent experts also played a decisive role in the successful outcome of the case concerning the third party patent.[516]

When small-scale production of concentrates for clinical testing was brought into focus, people from the *departments of Petrochemistry* and *Mechanical Engineering* were engaged in the project. The department of Petrochemistry had appropriate pilot plant equipment enabling the production of the first grams of pure EPA and DHA. This production revealed that the technology used for the second process step[517] would not be appropriate for full-

[516] I elaborate on this case in Chapter 12.6.3
[517] This process step was about isolating pure EPA and DHA from the EPA/DHA raw concentrate, see Chapter 12.2.2.

scale production. Therefore, people with the department of Mechanical Engineering were hired to investigate another method suitable for full-scale production. Based on initial experiments and trial productions, Breivik and his co-workers decided to collaborate with a *professor in France* and to perform pilot plant production at his firm. At the same time, project members realized that the production capacity for the first process step performed at the department of Petrochemistry could not meet the demand for pre-clinical and clinical studies. As a consequence, people from the department of *Chemical Engineering* and *Hydro Engineering* were engaged to identify potential trial production plants. Trial production was performed at *pilot plants* in Norway and abroad. After the acquisitions of *JC Martens* and *Jahres*, these fish oil companies played a major role in the manufacturing of *k85*. The encapsulation process was carried out at *R P Scherer*, a specialist company in Germany, while people at *Hydro Pharma* were engaged to do the packaging and release of the capsules. Hydro Pharma was also engaged to assist in the design and monitoring of stability studies.

Thus, the examples above show that the accomplishment of work pertaining to the activities named “development of product and production process”, “manufacturing facilities”, and “patents” in the systems model of the Omacor™ project (Ref. Figure 12.2.1) required the joint efforts of specialists across disciplinary, departmental, and organizational borders. The establishment of collaborative partnerships made it possible for Breivik and his colleagues at the Analytical department to accomplish tasks they could not pursue alone. These formal *project networks*[518] provided access to critical expertise as well as to necessary tangible resources (e.g. process technology, sufficient amounts of test substance for clinical testing, trial production plants, manufacturing facilities). As such, the project networks were necessary to successfully define and solve the open-ended tasks in question.

The chemical analysis work shed further light on purposive and instrumental types of networks while at the same time providing examples of how informal personal networks proved to be important for managing difficult challenges regarding the “pharmaceutical” and “commercial” challenges (Ref. Chapter 12.2).

Hydro researchers carried out the chemical analysis work in close collaboration with external competence groups. At the Hydro Research Center, Porsgrunn, the *Analytical department* and a new *Lipid Laboratory* dedicated to work solely on the analysis of omega-

[518] I regard *project network*, which I think of as a short-term combination to accomplish a specific task (Ref. Powell and Grodal, 2005), as an appropriate term for the formal networks forged to ensure requisite variety of expertise and other necessary resources.

3 products, were also engaged in the efforts. The research group of *Martens* was involved, as was the *Directorate of Fisheries in Bergen* (See Figure 12.6.1). Breivik and his colleagues regarded the opportunity to get independent analysis results from the latter institution as a great advantage.

Along with the professor in France mentioned earlier, a researcher at the University of Iceland and two professors in the US and Canada contributed with their competence. Harald Breivik got in touch with the two latter professors at a symposium on EPA and marine oils in May 1986.

Professor Ackman at the *Canadian Institute of Fisheries Technology* was known as the world-leading expert on marine oils. He headed the most internationally acknowledged laboratory for the analysis of omega-3 fatty acids, and his methods for chemical analysis were internationally recognized.[519] Breivik assumed that acquisition of these methods would be critical for dealing with questions surrounding purity, by-products, etc.[520] He and his colleagues made several visits to Ackman's laboratory to learn more about his methods, to compare his methods with the methods used at the Hydro Research Center, Porsgrunn, and at the Directorate of Fisheries, and to discuss relevant issues on analysis.

Professor Joseph was employed at the *National Analytic Issues Service (NAIS),* in the *Department of Commerce,* USA. She headed a laboratory that produced a substance similar to *k85* as a test substance for the National Institute of Health. According to the Freedom of Information Act, the NAIS-work was public, providing access to process information, such as complete laboratory journals on production and analysis of the concentrates, including a detailed description of the processes.

Hydro researchers considered their international network and personal contacts to be of great value and of decisive importance for the development of the project. The collaboration with internationally recognized experts on omega-3 fatty acids and pharmaceutical product development contributed to their success in dealing with the strict, comprehensive requirements for therapeutic pharmaceuticals. Close contact with these experts facilitated Hydro's acquisition of necessary *context-relevant skills* in terms of expertise regarding the requirements of Good Manufacturing Practice (GMP) (Ref. Chapter 8). In addition, the opportunities to discuss important project aspects with world-leading experts in the field gave Hydro researchers the opportunity to stay ahead of potential problems such as patent applications and the publicity on environmental pollution. The

[519] Omega3-konsentrater fra fiskeoljer. Status februar 1987. 1987-02-27
[520] Omega3-konsentrater fra fiskeoljer. Status februar 1987. 1987-02-27

significance of networks in the Omacor™ project is further illustrated through the coming example regarding the lack of standardized analysis methods for omega-3 concentrates.

As discussed in Chapter 12.2, project manager Breivik and his colleagues recognized that the project team had entered a field in which standardized analytical methods were lacking. Different methods for analysis of omega-3 fatty acids provided different results, meaning analysis results often varied from laboratory to laboratory. In addition, some firms used this situation deliberately to bring up omega-3 values in their products to win market shares.[521] Breivik therefore spoke in favor of taking active part in efforts directed at the development and definition of standard international methods of analysis for omega-3 concentrates.

To deal with the problem of lacking standardized methods of analysis for omega-3 fatty acids, Breivik arranged "Analysis meetings" and inter-laboratory tests. He believed that the orchestration of a close collaboration between experts in the field could influence the issue. In the following, I refer to this and other instrumental networks of specialists sharing similar skills and expertise as *community networks*.[522]

At the "Analysis Meetings," specialists on the analysis of marine oils and omega-3 fatty acids discussed and compared the different methods being used in order to develop procedures as similar as possible. Breivik also made contact with several laboratories worldwide to engage them in round-robin tests. These studies were followed by visits to laboratories where Breivik and his co-workers assessed the results and relevant competence issues. The overall network collaboration among omega-3 experts contributed positively to the development of official standardized methods for analysis of omega-3 fatty acids. Not only that, Breivik and his colleagues developed methods that were published in one of the leading US journals in the field and approved by a European expert group.

To summarize, the examples concerning chemical analysis in the Omacor™ project illustrate that the formation of *community networks* in the sense of clusters of specialists on omega-3 fatty acids were vital for managing critical project tasks. Such networks assisted Hydro researchers in learning *context-relevant skills*. In addition, experience sharing and

[521] In this connection, he also noticed that omega-3 products were suffering from decreasing interest and a bad image due to a great number of low-quality products in the market. Breivik concluded that the lack of standardized analyzing methods for omega-3 fatty acids might cause misunderstandings and excess work regarding collaborating partners and the documentation efforts.

[522] According to Powell and Grodal (2005), a cluster of individuals that share a similar set of skills and expertise has been dubbed a *network of practice* (Brown and Duguid, 2001) or a *community of practice* (Wenger, 1998). As such, the networks formed through the "analysis meetings" etc. appear as networks of practice. However, since the network terms mentioned refer to informal ties among members of a community or discipline, I dub instrumental networks of specialists within the same field *community networks*.

collective learning in the community networks provided important knowledge helping Hydro researchers to avoid critical problems and reach the goal concerning standardization of analytical procedures. In turn, this facilitated their capacity to deal with both the “pharmaceutical” and “commercial” challenge. (Ref. Chapter 12.5)

As discussed in Chapter 8, Breivik’s emphasis on establishing relevant professional networks also provided himself with considerable power of influence by means of *social capital*. Clearly, if it were not for his social capital, the project team would probably not have succeeded with the patent application process in the US and the adoption of Hydro’s analysis method as an official procedure. Statements from Professor Ackman at the Canadian Institute for Fisheries Technology, and Professor Joseph at the American Department of Commerce proved to be decisive for the approval of the patent when the US patent authorities opposed the *k85* patent.[523] Similarly, one of Breivik’s fellows in The Group of Experts for Fatty Oils and Derivatives for the European Pharmacopoeia Commission had a decisive influence on the outcome of a controversy concerning Hydro researchers’ work on methods for analyzing omega-3 concentrates. The expert representing his country was acquainted with the Hydro researchers. He knew their work was solid, and he verified their work. This verification implied that the objections were withdrawn. As project manager Breivik recounted:

> *…I remember once when Country A vetoed an issue we were working on. That was an unusual thing to do. But country A had shown a fair amount of protectionism in order to arrange things in a different way to protect their industry…The expert from country B agreed with us. Country C had not yet made up their mind.* ***In this and similar cases, the ability to convince the group members how the facts really are, is very important****…When the case was being discussed at a higher level, the representatives from country A had criticized the work that had been done. However, at the next meeting the leader of the delegation (from country C) returned, saying that “Our expert has read what the Norwegian specialist has written, and everything is verified.” In reality that caused the veto to be dropped. Thus, one might say, then, that there were cases when solid knowledge triumphover protectionism. But, it is quite a difficult thing to accomplish, because you have to be able to convince other team members.* ***If we did not have this point of contact, if the expert from country C did not know who we were, I think this would not have been the result. I*** *think it would not have happened, if there had been only a comment on a piece of paper of which you didn’t know the author…One should add that later we have obtained a good working relationship with the representatives of country A...* (Emphasis is mine)

[523] This case is further outlined in Chapter 12.5.3

Thus, the latter example shows that *informal*, mostly personal, networks established through professional meetings, publications, etc. was important channels of information gathering and sharing (Ref. Carlsson et al., 2002), but also an important source of power enabling the successful achievement of critical project tasks in the Omacor™ project. The influence of informal personal networks is further illustrated in the following section shedding light on the significance of contractual relations.

The Omacor™ project shows that the work concerning clinical and pre-clinical studies was accomplished through a large international professional network. Hans Krokan, Knut Heikås Dahl, and co-workers at the departments of Biotechnology and Pre-Clinical and Clinical studies played an important role, being responsible for protocol design, monitoring, and the follow-up of studies. At the same time, Hydro researchers often co-operated with external *Contract Research Organizations* (CROs). For instance, the pre-clinical studies were done at the University of Oslo and at an English contract laboratory because Hydro had no in-house laboratory facilities. Similarly, the clinical studies were carried out in *hospitals*. Thus, the *project networks* in question provided access to expertise and tangible resources helping Hydro people to accomplish activities necessary to procure marketing authorization.

Since omega-3 fatty acids had proved to be a "hot research" topic, the interest for clinical studies was great, and several researchers worldwide contacted the Hydro researchers, asking for test material. In this connection, the "blood pressure" study carried out at the University Hospital of North Norway in Tromsø is a striking example of how an informal network led to a formal network collaboration boosting the progress of the project.

Hans Krokan, the head of the department of Biotechnology was a doctor of medicine with a PhD in biochemistry, who had previously worked at the University of Tromsø (Ref. Chapter 12.2). Krokan was well informed about omega-3 fatty acids through current omega-3 research conducted by researcher colleagues at the University Hospital in North Norway, and this knowledge contributed to his great interest the Omacor™ project. In 1987/1988 one of his previous colleagues in Tromsø planned a "blood pressure" study on 100 patients. This professor, who was well informed on the omega-3 research activities at the Research Center due to his professional contact with Krokan, wanted to test the efficacy of *k85*. The blood pressure study, designed in cooperation by the two doctors, proved to be a very good and important study. "*In my opinion, this study was a big step forward for k85 - now Omacor™*", a project member stated. The study showed a beneficial efficacy on several cardiovascular risk factors, and was a decisive factor for preparation of the product patent (Ref. Chapter 12.2.4). Thus, similar to the case concerning the controversy around methods of analysis, this example illustrates that project members' informal personal networks embodied the potential of promoting the Omacor™ project in ways that probably no one would have expected. At the same time, it exemplifies that informal personal networks may trigger the establishment of contractual relationships.

So, to summarize, the Omacor™ project provide several examples of networks promoting innovation by stimulating the collective capacity to define and solve open-ended problems. *Project networks* facilitated access to required expertise and tangible resources. In addition, *community networks* stimulated learning of context-relevant skills and facilitated collective learning necessary to succeed with critical tasks. Finally, *informal, personal networks* provided power of influence by means of social capital or stimulated the formation of contractual relations giving access to important resources in fortunate, unexpected ways.

The PROSMAT "Die Life" Project

The PROSMAT "Die Life" project represented a pronounced interdisciplinary, cross-departmental, and inter-organizational network of specialists who all together possessed a wide variety of academic and practical competence (See Figure 12.6.2 below).

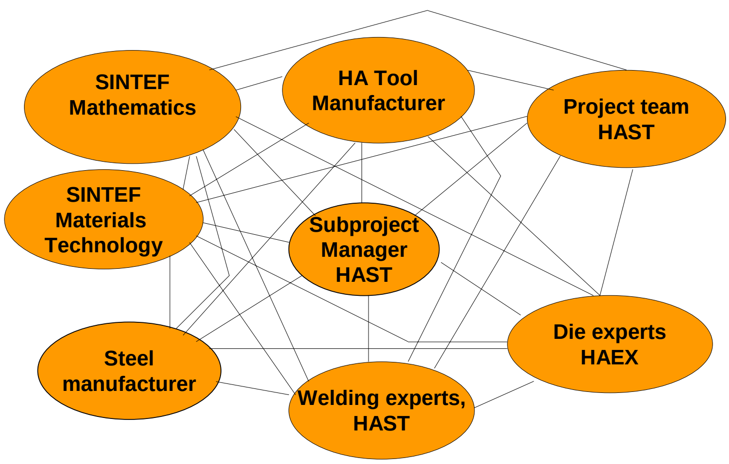

Figure 12.6.2 An Illustration of the Formal Project Network of Actors/Organizations in the "Die Life" Project

When faced with the die life problem at Raufoss Automotive in the late 1980s, Sigurd Rystad, who became subproject manager of the EXPOMAT and PROSMAT "Die Life" projects, concluded that the acute situation required a multiple approach where different ideas were tested in parallel. Rystad turned to *SINTEF Materials Technology* where he had a network of acquaintances as a result of his master's degree studies, his engagement as a research assistant, and his participation in several SINTEF projects over the years. He hired SINTEF researchers to conduct fracture mechanics studies to find out where and why cracks appeared. At the same time, Rystad engaged researchers at *SINTEF Industrial Mathematics* to do numerical simulations, in particular stress computations to find out if new die designs could reduce the stress. In addition to the SINTEF research activity, Rystad started an in-house project aiming to develop a method for repairing the dies to increase die life. The project group consisted of people in the *press plant*, collaborating with people from the *steel manufacturer* and *experts in welding technology*. The SINTEF researchers contributed with valuable input to the in-house project. In parallel, the practical testing provided feedback on the theoretical results. Thus, Rystad's establishment of collaborative partnerships made it possible for the HAST people to accomplish tasks they could not pursue alone. The *project networks* provided access to necessary expertise as well as to important tangible resources. Moreover, the examples above show that Rystad mobilized professionals in his informal personal network to recruit partners to the formal project network so characteristic of the "Die Life" project.

Through the EXPOMAT period the joint efforts contributed to considerable increase in die life. Still, increased competition from the steel industry implied that Raufoss Automotive had to make further improvements. Therefore, Rystad and colleagues spoke in favor of continuing the "die life" research in PROSMAT Extrusion. During the PROSMAT "Die Life" project, Rystad regularly arranged meetings and workshops, inviting *professors from NTNU* and the *University of Oslo*, *die experts from the HA Extrusion group*, *researchers from the HA R&D Center*, Karmøy, *researchers from the Automotive Research Center, SINTEF researchers*, *people from the steel manufacturer*, *people from the tool manufacturer*, *HAST people*, and *Automotive staff members* working on other forming processes. Figure 12.6.3 provides an overview of this network that I simply dub the *workshop network*.[524]

[524] Clearly, the formal and informal networks presented here partially overlap since several actors were parts in both types of networks.

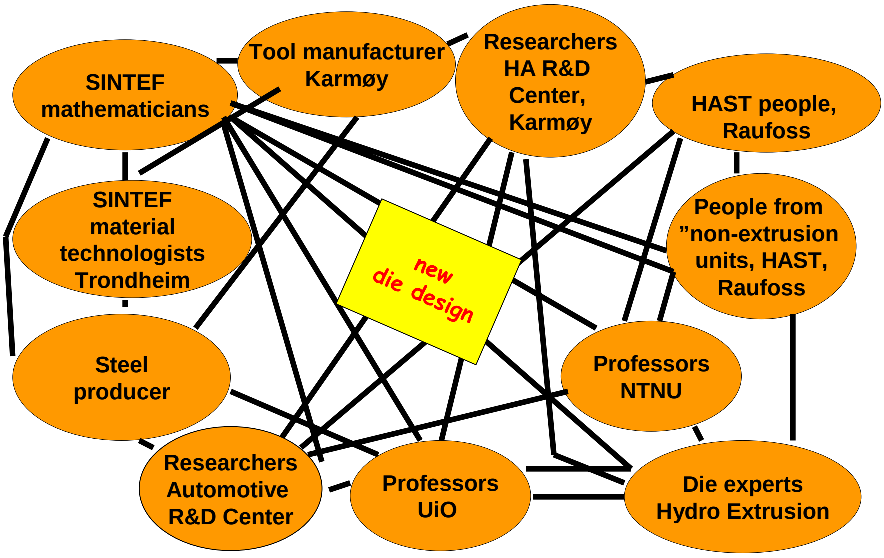

Figure 12.6.3 An Illustration of the Workshop Network of Actors/Organizations in the “Die Life” Project

To illustrate the significance of the workshop network, I briefly call attention to how collaboration and information sharing among its members contributed to solving two specific problems in the “Die Life” project. The first example is the workshop in which the idea of the New Die was proposed.

Initial stress analysis and practical tests soon revealed that the die design at that time had reached its limit with respect to die life; further optimization was not possible. Accordingly, a new die design was needed to avoid the cracking problem. This conclusion is recognized as a critical incident of the project, forcing rethinking. Facing this challenge, Rystad decided to arrange a large brainstorming meeting to generate ideas for a new die concept. Along with the project members, he invited several other people, for instance representatives from the steel manufacturer, the tool manufacturer, Hydro Extrusion, the Research Center at Karmøy, and Automotive staff members working on other forming processes. The brainstorming meeting resulted in a number of principally different die designs. The ideas were evaluated through numerical simulations, and further testing revealed that the so-called *New Die* appeared to be the most promising concept regarding reduction of stress in critical areas (“*hot spot stress*”). This concept was proposed by a person working on another aluminum forming process within Hydro Automotive. Similar to aluminum extrusion, this particular process involves the use of dies, putting strong demands on die design. As such, Rystad's emphasis on creating a professional network ranging beyond the formal borders of HAST, brought this particular principle into focus.

The development of test methods for accurate measurement of stress[525] in dies during press runs was another great challenge in the "Die Life" project. Appropriate test methods were seen as necessary for verification of numerical simulations. The work aimed at developing such procedures was retarded because of severe problems of finding suitable measuring equipment. In addition, searches for people with relevant competence on high temperature stress testing were negative. Accordingly, one concluded that no one else seemed to be capable of doing relevant measurements at operating conditions, i.e. extreme temperatures and pressure. Still, the project members continued their efforts. In March 1998 Rystad and colleagues arranged a large workshop on measurement techniques, inviting among others, *SINTEF researchers* and *professors at the University of Oslo*.[526] During the workshop the participants discussed a number of relevant measurement techniques. One of the professors proposed the use of a specific press sensor. Along with his colleague, who was member of the PROSMAT Extrusion steering committee, this professor had previously worked on test methods involving the sensor in question. The "Die Life" researchers agreed to use this technology as a basis for their development of test methods. The development of a "pressure sensor" became the main objective of a PhD study initiated in January 1999.

According to project members, the work on measurement technology provided important, new knowledge about the extrusion process. The "pressure sensor" is regarded as a main outcome of the project, "providing unique possibilities for looking into the process during aluminum extrusion."[527] Besides, the corresponding development of high-temperature measurement expertise is regarded as a pioneering event.

To summarize, the "Die Life" project shed light on instrumental networks facilitating the definition and solution of vital open-ended problems. All together, the formal project network and the larger workshop network enabled HAST people to accomplish tasks they could not pursue alone. The networks gave access to important expertise, resources and idea assisting the HAST people in managing difficult problems. The "Die Life" project also illustrates how informal personal networks of professionals contributed to the formation of contractual partnerships.

[525] According to PROSMAT: New Modeling Techniques for the Future Extrusion Technology. Project report 1999, measurement of strain, relative movement, and pressure is mentioned.
[526] Minutes of Meeting. Workshop 1998-03-18
[527] 2001 Report NFR HA R&D Materials Technology.

The "Bearing Channel" Project

Similar to the "Die Life" project, the "Bearing Channel" project highlights the importance of *project networks* including academic researchers as well as professionals with practical experience. As a project member put it: "*I am totally confident that the PROSMAT project would not have been that successful if it wasn't for the close connection to the hands-on projects!*"

Figure 12.6.4 illustrates the overall interplay of actors/organizations collaborating in a network of *project networks* including the PROSMAT "Bearing Channel" project, Hydro projects, and a large EU project.

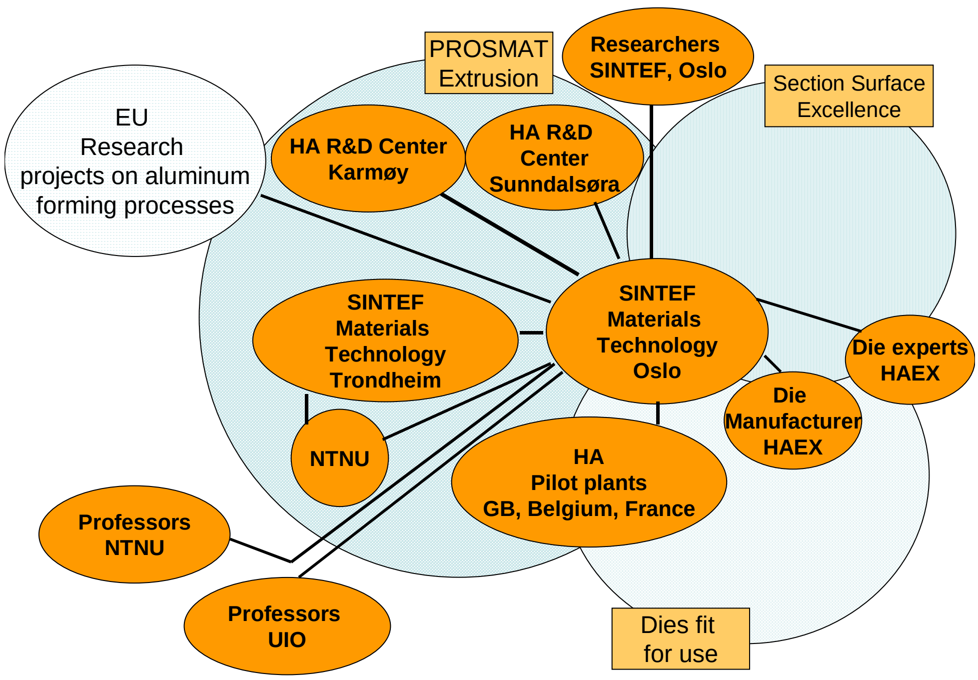

Figure 12.6.4 A Network Illustration of Actors/Organizations in the "Bearing Channel" and Related Projects

Along with subproject manager Trond Aukrust, working on numerical simulations, a group of eight to ten researchers at his *SINTEF department* and the *HA R&D Centers* at *Karmøy* and *Sunndalsøra*, were involved in the project. The SINTEF researchers also benefited from their joint location with several research groups with a tradition of interdisciplinary teamwork. This compact pool of researchers, reflecting characteristics of the *invisible college* (Ref. Powell and Grodal, 2005) boosted a large degree of informal communication among SINTEF researchers. As the manager of the *SSE* project explained:

> *…I used SINTEF in all directions. The SINTEF people in Oslo represent a compact research group including physicists, chemists, opticians, material technologists and mathematicians – and they are all located in one building…Originally, this was one*

> *single institute with a strong philosophy of working across disciplines…The professional and social contact were close…That was a great advantage, because whenever you were stuck, you could get help… For instance, if I faced something I didn't understand, I consulted a person working on a similar issue, getting enough input to grasp the relevance to my case and use it in the project…Working in such a research environment is really an enormous strength…*

Likewise, subproject manager Aukrust and his colleagues had close informal contact with *professors at NTNU* and *the University of Oslo*, in particular during the pre-study, when they discussed approaches to modeling of friction in the bearing channel.

Furthermore, Aukrust and his SINTEF colleagues took part in the Hydro projects called "Dies Fit for Use" (*DFU*) and "Section Surface Excellence" (*SSE*) where, among other people, *HAEX die designers* and *the HAEX die manufacturer* were involved. The *SSE* project concerned problems related to surface defects, while the *DFU* project aimed to determine rules for die design that could give optimum productivity, flow balance, and surface quality. As such, Hydro Aluminium Extrusion could benefit from a close interplay between the "Bearing Channel" project and the Hydro projects. The in-house projects focused on specific aspects of surface defects, while the "Bearing Channel" project was directed at developing a better fundamental understanding of the mechanisms leading to surface defects in the first place. Although the formal project boundaries were clear, project members perceived the actual boundaries as fuzzy. The three projects therefore constituted a seamless web of interwoven *project networks*. I now make a further description of the project networks and the activities involved.

The study of mechanisms behind surface defects was a major activity throughout the PROSMAT period. Along with Aukrust and colleagues at SINTEF Materials Technology, Oslo, a postdoctor candidate at *NTNU/SINTEF Materials Technology*, Trondheim, was engaged in these efforts. He was a PhD student in the EXPOMAT period and had developed a fruitful technique for studying dies by splitting them in two. He continued this work in PROSMAT, running large experimental series at the SINTEF laboratory press based on his split die technique. The SINTEF researchers studied industrial dies with surface defects, aiming at finding a connection between the respective surface defects and the specific die characteristics that had created them. Through the *SSE* project, they were provided a large number of industrial dies that had been scrapped because of wear. The die studies enabled the generation of hypotheses for the formation of surface defects that were used in the development of numerical models that could predict surface defects.

Based on the experimental studies and numerical simulations, the SINTEF researchers worked out recommendations for design and maintenance of dies. These recommendations had to be verified and validated through practical testing at pilot plants, and these efforts were carried out in close collaboration with the in-house projects. A number of dies were manufactured for testing at the *SINTEF laboratory press*, Trondheim, and at *pilot plants in Great Britain, Belgium, and France*.

According to project members, the joint academic-hands-on verification/validation efforts was a sound working method, combining the best of the academic world with practical industrial projects. Practical testing provided the possibility for validation of the modeling results and vice versa. In addition, the mathematical models contributed to a good understanding of what happened inside a die during extrusion.

Thus, the *project networks* referred to enabled Hydro Aluminium Extrusion to complete tasks they could not achieve alone. The networks provided access to a great variety of practical and academic competence, as well as to necessary tangible resources (e.g. defect industrial dies, laboratory facilities, and pilot plants) enabling the accomplishment of important tasks.

During the PROSMAT period, Hydro Aluminium and SINTEF were also involved in EU projects focusing on generic issues related to aluminum forming processes. Aukrust had colleagues that were engaged in these projects, too. As such, he and his colleagues obtained relevant knowledge on material technology developed in the larger EU projects.

So, to summarize, the "Bearing Channel" project may be regarded as one node in a web of projects stimulating formal and informal collaboration and information sharing across disciplinary, departmental, organizational, and formal project borders. The project calls attention to formal project networks as well as informal *invisible colleges*. Invisible colleges represented important channels for information sharing, providing important knowledge of relevance for the "Bearing channels". Likewise, project networks, in particular, seamless webs of interconnected project networks embodied critical expertise and tangible resources assisting HAEX to accomplish tasks in-house experts would not have manage to complete alone.

12.6.3 Networks in Terms of Strategic Alliances

In this chapter I discuss how people in the Omacor™ project created strategic alliances to deal with challenges regarding activities reviewed in Chapter 12.2. More specifically, the difficulties surrounding the "*k85* patent", the work directed at developing official methods of analysis, and efforts aimed at obtaining financing of the project are reviewed.

Approval of the "*K85* Patent"

As previously outlined, getting the "*k85* patent" approved, proved to be a real challenge, not least because of the so-called Dyerberg patent. Figure 12.6.5 below illustrates three controversies forming parts of this case and the emerging heterogeneous actor-networks (Ref. Latour, 1987). The controversies are symbolized with a set of claims where the red and green bubbles represent the voices of the dissenters (Ref. Latour, 1987) and Hydro people respectively. The thickness of the accompanying lines indicates the actors' relative force vis-à-vis each other.

The Dyerberg patent did not *necessarily* represent a threat to the "*k85* patent", but as project manager Harald Breivik remarked: "*The patent would make it a lot more difficult to explain to the world that our patent did not represent a conflicting one*".

The inventors developed a set of parallel strategies to deal with the problem. The Dyerberg patent included a pharmaceutical formulation in which the concentration of EPA was a least 50 percent of the fatty acids. Therefore, the Hydro researchers decided to adjust the specifications of EPA/DHA so that their formulation contained less than 50 percent EPA. In this way, *one* difficulty was eliminated (illustrated by change of relative power in Figure 12.6.5).

Next, the inventors concluded that they had to put effort into well-defined solutions concerning claims about the inventive step of the patent. Omega-3 fatty acids had been the focus of research for more than fifty years, and all relevant effects on cardiovascular diseases had previously been described. As such, the Hydro inventors faced the following question: How do we write a patent application for a product that apparently is not drastically different from other omega-3 products describing known effects? The Hydro researchers claimed that their omega-3 concentrate was a unique, concentrated substance that had a *surprisingly* advantageous effect on all the relevant risk factors for cardiovascular diseases, compared to ordinary omega-3 products. In addition, they argued that their product provided *the same effects with a considerably smaller volume* of omega-3 fatty acids. The inventors also reported indications of a *surprising synergism* between the action of EPA and of DHA.

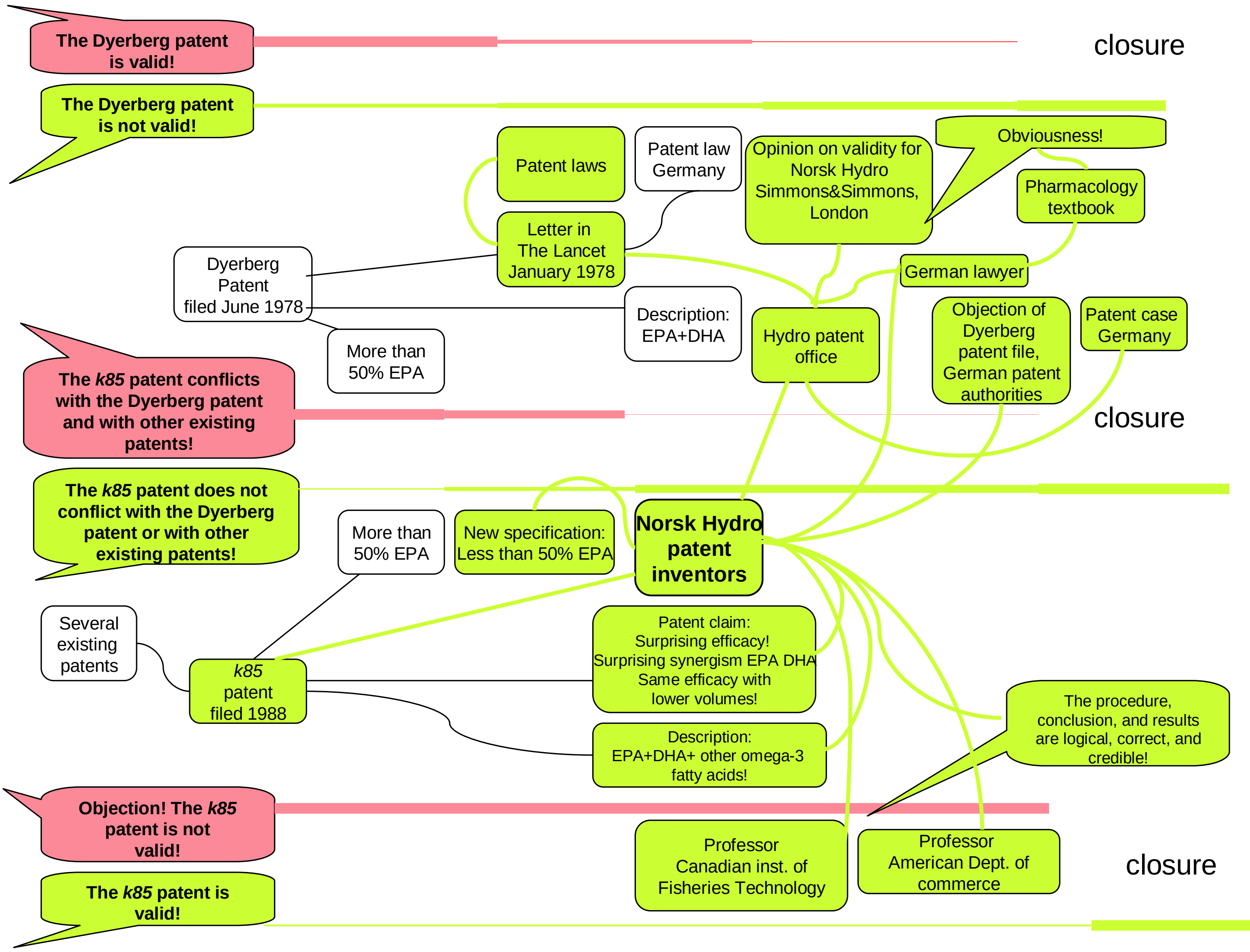

Figure 12.6.5 Controversies Regarding Patent Work

Finally, they "made a little twist" to obtain a favorable position in relation to the third party patent. As Børretsen explained:

> *…After all, we patented almost the same as the Dyerberg patent. But we made something different: We defined a product that contained other omega-3 fatty acids, too! You see: There are a lot of omega-3 fatty acids in low concentrations that you cannot get rid of. Thus, our actual description was the real clue concerning the two patents; they described EPA and DHA, whereas we made a description of EPA and DHA* **plus** *the other omega-3 fatty acids!...*

Thanks to these strategies, the Hydro inventors managed to strengthen the position of the "*k85* patent" vis-à-vis the Dyerberg patent and other patents existing at that time (Ref. the change of relative power indicated in Figure 12.6.5).

The "*k85* patent" was strongly opposed by the US patent authorities. "*Apparently, the efficacy of the concentration was surprising*", Breivik commented. A new patent that was not yet public made the argumentation particularly difficult. Breivik had to make a sworn declaration to the patent authorities, declaring that if he were not right, he would be imprisoned. Faced with the strong opposition in the US (lower part of Figure 12.6.5), Hydro asked Professor Ackman at the Canadian Institute for Fisheries Technology, and Professor Joseph at the American Department of Commerce, to give their opinions on the validity on the patent claim. Both professors supported the content of the patent, claiming that the procedure, the results, and the conclusion were logical, correct, and credible. These statements convinced the US patent authorities, and they finally approved the patent. Commenting on the successful outcome of the case, Breivik said:

> *…Actually, Professor Joseph claimed that according to her calculations, I had been too careful. Professor Ackman said the same using his words.* ***In this case, Norwegian professors would not have been of any help. Joseph was at the American Department of Commerce. Her word had a much greater weight than Norwegian professors. Thus, I feel that having good personal contacts was decisive.*** *You cannot just work on your own, because then you get lost when you have to face patent lawyers and others. But having a history that was documented with statements from other people was very important…*(emphasis is mine)

Furthermore, the inventors found that the Dyerberg patent represented common knowledge existing at the date it was filed. Accordingly, they decided to put effort into having the patent declared null and void. Bernt Børretzen and people from the Hydro Patent Office handled the patent case that proved to be a difficult, long-lasting process.

The first promising moment was when the head of the Hydro Patent Office found a letter in *The Lancet,* a medical journal, from January 1978. Here, the inventors made public results related to their patent filed in June 1978, five months later. According to patent regulations, information previously published could *not* be patented. The letter proved that the inventors knew about the results in advance, implying that this part of the work was completed (see change in relative power, upper part of Figure 12.6.5). However, at that time, Germany had some special regulations allowing patenting within six months after publication. As Germany was considered a great potential market, Hydro chose to continue the process. They contacted the German patent authorities, filing a protest on the patent. They also engaged lawyers in London to give an opinion on the validity of the patent. These lawyers concluded that the patent could successfully be disputed on the grounds of *obviousness*, in the light of common general knowledge existing at that date. This formed a basis for further argumentation.

At this time, the patent had been licensed to a Japanese firm. It had not yet been approved in Germany, and this was a favorable situation for Hydro. Hydro's protest was strongly opposed by the Japanese firm and vice versa, resulting in a lengthy correspondence between the German patent authorities and the respective parties. Maintaining their protest in court, Hydro was strongly opposed by several respected researchers testifying for the opposing party. In the words Børretzen,"*We argued that this was prior art, and then they claimed that they did not know – and they were Nobel Prize winners! Thus, such arguments are very difficult".* Nevertheless, the German patent authorities supported Hydro's protest. In addition, the German lawyer engaged by Hydro found a pharmacology textbook predating the Dyerberg patent. "Then it was obvious," Børretzen said, explaining: *"Publication is one thing. However, when something is described in a textbook, then it obviously is prior art".* This finding was decisive for the court's conclusion that the patent represented a "discovery" that was obvious to anyone skilled in the arts. So, Hydro finally won the case.

Viewing the patent example in light of Latour (1987), it is evident that the Hydro patent inventors enrolled actors and actants in order to reach two goals: 1) *Approval of "the k85 patent"*, and 2) *Having the Dyerberg patent declared null and void*. When writing the patent claim, they aimed at tailoring the text in such a way that it catered to the criterion of novelty. This criterion represented an *obligatory passage point* (ibid.) for all patent applicants, and it made it easier for Hydro to anticipate relevant objections. Thus, to convince patent authorities about the validity of their patent, they *translated their interests* to fit in with the patent authorities' *explicit* interests (*Translation One: I want what you want*, ref. Latour, 1987). In other words, Hydro chose the easiest means of enrolling the patent authorities, namely to let themselves be enrolled by them! They realized that the initial formulation had to be changed and that they had to formulate claims that could withstand dissent. Obviously, they also emphasized the importance of building strength by referring to as many inventive features as possible. Referring to "*surprising efficacy*", "*surprising synergism*", "*same efficacy with a lower volume*", and "*EPA and DHA **plus** other omega-3 fatty acids*," they tried to persuade the patent authorities that "the *k85* patent" should be approved. Hydro managed to convince the patent authorities in several countries except the US.

Facing rejection from the US patent authorities, Hydro enrolled other allies to support their claim: *Professor Ackman*, world-leading expert on marine oils heading the most acknowledged laboratory for analysis of omega-3 fatty acids, and *Professor Joseph*, employed at the National Analytic Issues Services, The Department of Commerce, US. Armed with statements from these internationally recognized experts, possessing greater authority than Norwegian professors, Hydro managed to obtain approval in the US.

Likewise, Hydro managed to declare the Dyerberg patent invalid by means of a proof race involving a large number of actors and actants. Supported by the *Hydro patent office*, the *patent regulations in several countries*, *The Lancet* from January 1978, and *the date of filing for the Dyerberg patent*, the Hydro people succeeded in making the Dyerberg patent void in numerous countries. Yet, their claim was not sufficient to resist German patent laws. Therefore, Hydro continued to recruit new allies to make their claim resist all efforts to break it apart: The German patent authorities and the British law firm *Simmons and Simmons*. In turn, these organizations provided additional allies: *Support for the patent protest* and a *legal statement claiming that the Dyerberg patent represented obvious knowledge*. Still, this heterogeneous network of alliances was not sufficient to resist the opposition from the Japanese firm, the Dyerberg patent inventors, or their Nobel Prize-winner friends. Hydro's claim of "obviousness" needed further support, and the "older" *pharmacology textbook*, representing the very incarnation of common knowledge, proved to be the ally that finally tipped the balance of force in Hydro's favor.

Methods for Analysis of Omega-3 Concentrates

The lack of standard methods for analyzing concentrates of omega-3 fatty acids made the issue of chemical analysis extremely complex. Different methods provided different results, and the absolute difference between results from different test procedures normally increased with increasing concentrations of the object being analyzed. Accordingly, label claims did not necessarily contain adequate information for the customer, since specifications were always related to the actual test procedure used. The situation was difficult. In the words of Harald Breivik:

> *…Concerning k85, our result was 84 percent EPA plus DHA, whereas analyses performed by others showed 88 percent. Thus, it was difficult, then, to sell the product to someone whose analysis showed only 80 percent…*

The fact that some firms tried to benefit from the situation, made the situation even more difficult. As Breivik reported in February 1987:

> *…It seems that some use this fact deliberately to exaggerate omega-3 values. For instance [name of company] states that their product contains 50 percent EPA plus DHA, while the real value at the turn of this year was 42-45 percent. According to [name of professor], the company has been aware of this for a long time. However, instead of changing their product declaration, they worked at improving the process. In reality they sold a "50 percent concentrate" (winning corresponding market shares) months before they obtained the promised concentration…*[528]

Facing this situation, Breivik concluded that lack of standard methods of analysis might cause misunderstandings and excess work regarding collaborating partners and documentation efforts.[529] He spoke in favor of taking active part in efforts directed at the development and definition of appropriate official methods for analyzing omega-3 concentrates (see Figure 12.6.6 below).[530] Such efforts would give Hydro additional professional credibility. At the same time, active involvement could prevent approval of methods of analysis that might "discriminate" against *k85* and other high-concentrates of omega-3. A strong overall emphasis on analysis methods and documentation of the quality of *k85* was also considered necessary to deal with the low-quality omega-3 products in the market. In the late 1980s, several companies engaged in the production of omega-3 because they thought this was "easy money", as a project member put it. Low quality gave omega-3 products a bad reputation, meaning it became important to create a spotless image of Hydro's products.

The chemical analysis work was carried out by several Hydro researchers collaborating closely with external national and international competence groups (Ref. Chapter 12.6.2, see also Figure 12.6.6). The Hydro researchers made several visits to Professor Ackman and Professor Joseph's laboratories to learn about relevant methods of analysis and procedures concerning the directions of GMP. In addition, arranging "Analysis meetings" and inter-laboratory tests became an important strategy related to the efforts of developing standard methods of analysis. The "Analysis meetings" were held at the Hydro Research Center on the initiative of Breivik and his colleagues. Here, people from several research groups working on analyses of marine oils/omega-3 fatty acids discussed and compared the

[528] Omega-3-konsentrater fra fiskeoljer. Status februar 1987 1987-02-27
[529] Prosjektoppdrag: Finkjemikalier fra fiskeavfall. Budsjett 1988
[530] Konsentrater av omega-3 fettsyrer. Status april 1988 1988-04-27

various methods being used, aiming to establish common procedures. The Hydro researchers believed such meetings could influence this issue. The researchers also made contact with several labs worldwide to engage them in comparative studies.

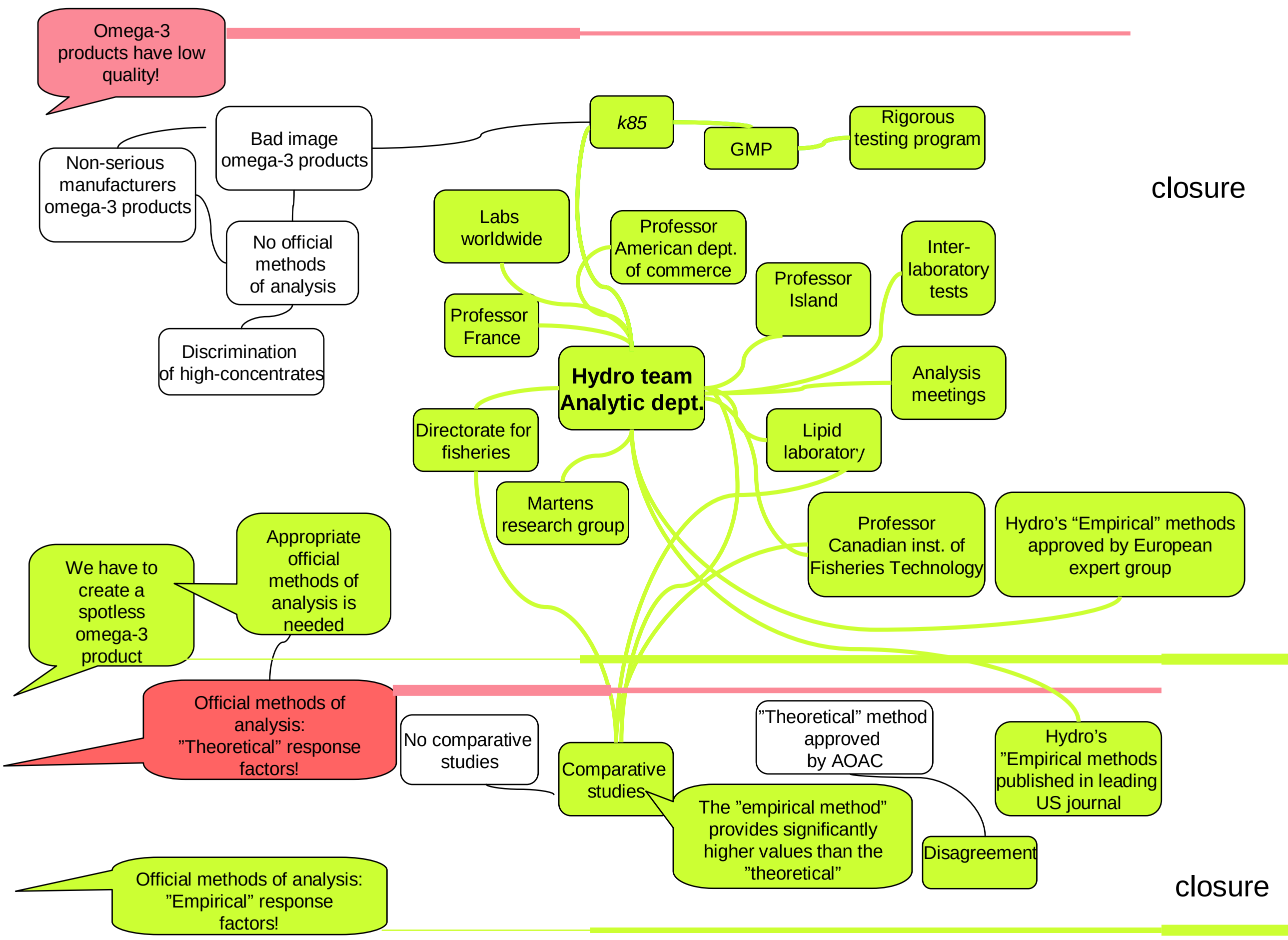

Figure 12.6.6 Controversies Regarding Analysis Methods

The studies were followed by visits to the laboratories where the results and competence issues were assessed. The Hydro researchers were also invited to participate in comparative studies, for instance in a large round-robin test on EPA/DHA arranged by the *American Oil Chemists' Society* and *The Association of Official Analytical Chemists (AOAC)*. The Hydro Research Center was one of 25 laboratories participating in the test, and the invitation was considered as a sign that Hydro's work was internationally recognized. The study was based on a new method for chemical analysis in which so-called "theoretical response factors" were assumed to be used (hereafter called the "theoretical" approach).[531]

531 "Konsentrater av omega3-fettsyrer. Status april 1988." 1988-04-27

The "theoretical" approach, developed by Professor Ackman in Canada, had been proposed as an official AOAC-method (Ref. the controversy surrounding "theoretical" versus "empirical" methods shown in Figure 12.6.6).[532] Commenting on the method, the Hydro researchers claimed that the "theoretical method" would discriminate against high-concentrates such as *k85*, providing incorrect values and values that were too low for such products. Speaking in favor of an "empirical approach," they argued that the "theoretical" procedure should not be used. Breivik and his colleagues also concluded that it might be essential to demonstrate a significant difference between the "theoretical" and "empirical" approach.[533] At this time, at the end of 1988, Breivik realized that the "theoretical" approach method might be approved within a year. He proposed immediate action in the form of comparative studies. According to Professor Ackman, such studies had not yet been performed. Breivik's plan was as follows: If it turned out that the proposed method yielded lower results than the Hydro researchers found to be correct, the researchers would contact Professor Ackman and Professor Joseph in efforts to influence the content of their report.[534] Brevik also suggested that Ackman could analyze *k85* by using different methods to carry out some of the studies, following up with a written comment on behalf of the Hydro researchers.

Comparative studies at the Hydro Research Center and The Directorate of Fisheries confirmed that the "empirical method" yielded significantly higher values than the "theoretical" one. In this connection, the researchers regarded the possibility of getting independent analysis results from the latter institution as a great advantage. The comparative studies were followed by a visit to Professor Ackman's laboratory to discuss the methods and to have additional analyses performed. The new analysis confirmed the earlier findings. Still, the Hydro researchers did not gain any ground with their claims. Within a short time, the "theoretical method" was approved by AOAC. Breivik noticed that many researchers disagreed with the decision, questioning the validity of the method.

The Hydro researchers continued their efforts at improving the methods for chemical analysis. Within a few years they managed to develop methods that were published in one of the leading US journals in the field, and a European expert group approved the methods. One of the methods was an improvement of a method developed by Ackman and Joseph.

[532] Konsentrater av omega3-fettsyrer. Status april 1988. 1988-04-27
[533] Report from The American oil Chemists' 79th annual meeting, 88 06 15
[534] Report from a telephone conversation between professor Ackman, Breivik, and one of Breivik's colleagues, 1988-11-25

So, the Hydro researchers finally managed to turn the case in favor of their own interests and points of view concerning methods of analysis of omega-3 products.

The overall emphasis on analysis and documentation of the quality of *k85* in accordance with GMP, contributed to Hydro earning considerable international recognition, and provided the Hydro product with a spotless image. According to a Pronova Biocare brochure for Omacor™ published in 1999, no other omega-3 products had undergone such a rigorous testing program to meet international documentation requirements for pharmaceutical products.[535] Thus, the analysis work contributed to giving Hydro a competitive advantage in the market of omega-3 products previously associated with non-serious actors and low-quality products.

Like with the patent case, the analysis work shows that Hydro researchers enrolled human and non-human actors to support their interests and points of view regarding methods of analysis of omega-3 concentrates. They enrolled a large number of experts providing the competence and facilities necessary to transform the following claims into facts: 1) *Different methods of analysis yield different results, and the absolute difference increases with increasing concentration*, and 2) *There is a need for appropriate official methods of analyzing omega-3 concentrates*. By means of inter-laboratory tests, Hydro researchers intended to recruit allies in terms of analysis results proving claim 1, i.e. making it more of a fact (Ref. Latour, 1987). Evidently, the Hydro researchers also aimed at increasing the strength of their claim by performing a great number of tests, thereby enrolling as many external allies as possible. However, numerous test results in themselves were not sufficient to resist trials of force. *The results had to be presented in such a way that a large number of experts were persuaded by the problematic diversity*. Arranging "*Analysis meetings*" in parallel with the *round-robin testing* served as an appropriate strategy to convince authorities in the field and thereby keep the enrolled allies in place (ibid). Here, the researchers staged for a thorough discussion, comparison, and evaluation of the test methods and the results. By allowing all the test results to come on the scene simultaneously, they attained a more favorable position towards prospective dissenters. Instead of acting as *spokesmen* (ibid.) of the diversity, Hydro researchers convincingly staged a situation where the series of results and methods could speak for themselves. In this way, the researchers could enroll a large group of strong allies, namely experts supporting their point of view.

[535] "OMACOR™. An introduction. A new edition for a refined treatment." Published by OCC, London 1999, on behalf of Pronova Biocare.

Yet, having convinced several experts about claim 1, the researchers faced the difficulty of convincing experts of what should be the "correct" official method of analysis ("The empirical method"). Realizing that the "theoretical" approach had strong support, the Hydro researchers aimed at enrolling *new* allies to tip the balance in their favor. Again, they emphasized the importance of comparative studies. To build strength, they engaged The Directorate of Fisheries and Professor Ackman's lab to conduct independent analyses. These studies supported Hydro's point of view and mobilized Professor Ackman and Professor Joseph to influence the case. Still, the series of allies "*test results from Hydro*", "*test results from the Directorate of Fisheries*", "*test results from the Canadian Institute of Fisheries Technology*", "*Professor Ackman*," and "*Professor Joseph*," was not strong enough to withstand dissent.

Hydro did not give up, though. I do not have much empirical data on their continued efforts, but I suppose that strategies similar to those outlined here contributed to make their "empirical method" an official method of analysis.[536] As such, they finally managed to transform their point of view into an *obligatory passage point* (Ref. Latour, 1987), making the behavior of "omega-3 analysts" predictable.

Obtaining Supervisory Support and Financing

The final example in this chapter concerns efforts directed at obtaining necessary supervisory support and financing in the Omacor™ project (see Figure 12.6.7 below).

Challenged by the fatty by-product, the head of "Fine Chemicals from Biomass", Sigurd Gulbrandsen, contacted Bernt Børretzen at the Hydro Research Center, Porsgrunn, asking him if the fat could be exploited. Børretzen suggested that the omega-3 fatty acids in the fat could form the basis for a high-concentrate omega-3 "heart medicine." He argued that the use of omega-3 for medical treatment was a new, expanding field with great potential. The "input" from Børretzen, *the project champion*[537], became part of a document on fine chemicals from fish waste that Gulbrandsen wrote in May 1984. The two Hydro people presented the project idea to top managers at the Hydro Corporate Center, and the concept was well received. According to one of the top managers, Hydro had always intended to

[536] I do not have much knowledge on the practice surrounding official methods of analysis. Therefore, I do not know whether the approval of the "Empirical" methods as official methods of analysis made the "Theoretical" methods invalid or not. However, the point in the current analysis is to demonstrate that heterogeneous actor-networks played an important role in the analysis work.
[537] Ref. Chapter 8

enter into pharmacy, but the expansions into light metal alloys, PVC, etc. had interrupted these plans.

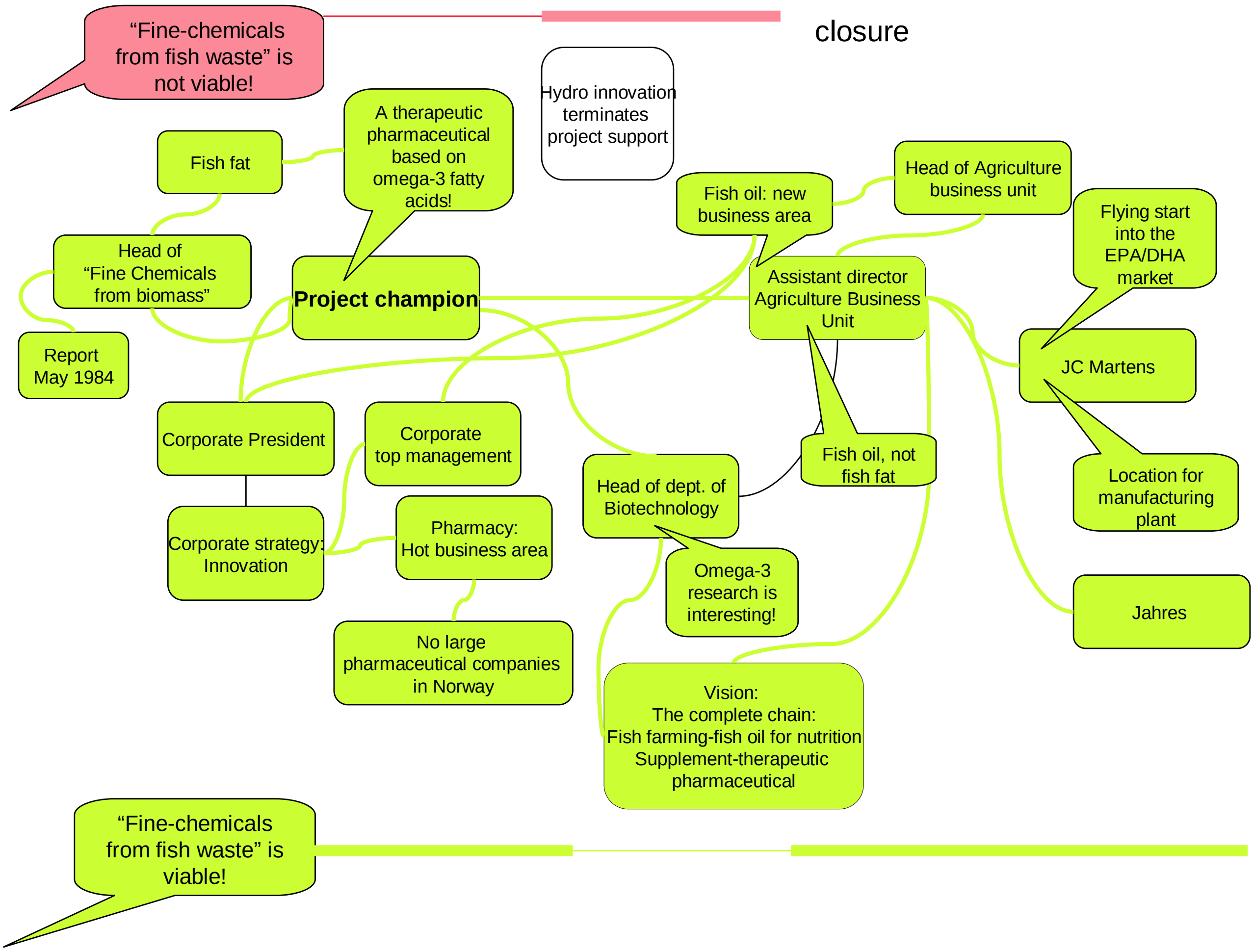

Figure 12.6.7 Controversies Regarding Financing and Support

The Corporate President, having entered into his position some months before, was also exited. As Corporate President, he had immediately brought innovation into focus, arguing that the innovation strategy should include both innovation within traditional business areas and expansion into new areas. At this time, pharmacy was a "hot" business area subject to great interest from the top management in Hydro. The profits in the pharmaceutical industry were twice as large as in other industrial areas. Hydro also appeared to be in a beneficial position since there were no large pharmaceutical companies in Norway. Accordingly, the proposal of a project directed at exploring fine chemicals from fish waste fit well with the visions of top managers. This situation was decisive for turning the project idea into reality.

During its first year, the Omacor™ project got another enthusiastic supporter, *Hans Krokan*, the new head of the Department of Biotechnology. Krokan was a doctor of medicine with a PhD in biochemistry who had worked at the University in Tromsø for several years. Responsible for the biotechnological product portfolio, Krokan concluded that new projects were needed in order to promote activity within his department. He soon got to know about the omega-3 research at the Research Center, finding it to fit well with his plans. Krokan was already well informed about omega-3 fatty acids through current research conducted at the University Hospital of North Norway in Tromsø. From his perspective, omega-3 fatty acids represented an attractive research area involving "the interesting cross-section of biochemistry, nutrition, and clinical medicine," as he put it, as well as products with a greater long-term potential than traditional medicines.

In September 1986, the future of the project appeared to be promising. Project manager Harald Breivik reported that researchers did not know of anyone who had developed omega-3 concentrates as far as they had.[538] At the same time, he argued that a lot of chemistry had to be done, implying the need for more people. Still, Hydro Innovation decided that they would not support further work on the project. Despite strong indications of a high efficacy in omega-3 fatty acids, the project owner questioned the business aspect of the project. As the head of Hydro Innovation explained:

> *…Our attitude was to test things out to see if they worked…From a business point of view, we questioned the commercial viability of this project … Is it possible to protect the intellectual property rights to these effects in such a way that you can earn enough money in the other end to recover the investments related to documenting the effects? We did not believe that and terminated our support of the project. History has shown that our decision was correct...*

The project members disagreed with this decision. The Omacor™ project did not have an obvious organizational home within existing business areas, and project members put efforts into obtaining a new project owner. In particular, they directed their attention to the Agricultural Business Division and the Vice President who had been hired by Hydro some months earlier. The Vice President, who had been the manager of a large fish meal company, was familiar with research on fatty acids, and he was acquainted with fish oil and fish feed in general. In Hydro he headed the section of salmon farming and fish feed.
Like Hans Krokan, heading the department of Biotechnology, the Vice President was exploring new opportunities within biotechnology at that time. He was informed about the

538 Produksjon av ω3-konsentrater, EPA og DHA. Status august 1986. 1986-09-02

omega-3 research through discussions with Krokan, Bernt Børretzen (the project champion), project manager Harald Breivik, and Sigurd Gulbrandsen heading “Fine Chemicals from Biomass”. The Vice President was convinced of the potential of the project, and he found synergy with the other marine activities in his department. In particular, he was enthusiastic about the proposed idea of having a complete chain, from fish farming, via fish oil intended for nutrition supplement, to an omega-3 high-concentrate as a therapeutic pharmaceutical. According to project members, the Vice President and Krokan, heading the department of Biotechnology, became a strong team, able to exert considerable influence on the further path of the project. They often discussed visions related to omega-3 fatty acids and other fish activities. Based on his trade competence, the Vice President argued in favor of using commercial fish oil rather than fish waste as raw material. Therefore, when the fish oil company JC Martens was for sale in the fall of 1986, he considered acquisition of this company to be a natural strategy. This idea was also motivated by the possibility to get a location where Hydro could start building a manufacturing plant.

Visiting the company to take a closer look at the production facilities, the Vice President, Krokan, and Breivik concluded that the plant provided interesting opportunities, including a “*unique possibility for a flying start into the EPA/DHA market*”, as one of them put it. The Vice President presented the case to his superior, the head of the Agriculture Business Division. He found the idea of having fish oil as a business area very interesting. He responded positively to the plan of buying JC Martens, as did the company president and other corporate managers. Also, project champion Børretzen played a major role in convincing the top managers of entering into the fish oil business.

At the end of 1986 Hydro bought JC Martens. The acquisition was described as a “step in the direction of giving marine biochemistry higher priority”.[539]At the same time, the responsibility for the Omacor™ project (called “Fine Chemicals from Fish Waste” at that time) was transferred to the Agriculture Division, located within the Biotechnology section headed by the Vice President. Thus, the Agriculture Division became the new sponsor of the project. “*And we said: OK! The Agriculture Division makes its own decisions*”, the head of Hydro Innovation remarked.

A year later, the Vice President organized the acquisition of JC Martens’ main competitor, Jahres fabrikker, which was for sale. Through these purchases Hydro became

[539] Profil 3/88

one of the largest fish oil companies worldwide, bringing the Omacor™ project a "quantum leap forward," as one of the project members put it. Characteristically, the project title "Fine chemicals from fish waste" was changed to "Omega-3 concentrates". Thus, the controversy around the Omacor™ project in 1986 reached closure.[540]

Similar to the other cases, this final example illustrates well how Hydro personnel built strategic alliances to gain ground. In particular, it demonstrates the process of translating their interests to fit with the enrolled actors. To get the necessary support for the idea of commercial utilization of the fish waste, project champion Børretzen and Gulbrandsen, heading "Fine Chemicals from Biomass", tailored the idea to suit the interests of corporate management. As a member of the corporate T-staff, Gulbrandsen was well acquainted with the new corporate strategy and the particular interest in pharmaceutical industry. Similarly, Børretzen, who knew several people at the Hydro headquarters, was well informed about the current strategic discussions. Despite the fact that several compounds appeared to be commercially interesting, the actors therefore emphasized the idea of a therapeutic pharmaceutical based on omega-3 fatty acids. They translated their interests to fit the *explicit interests* of the corporate management, letting themselves be enrolled by them (Ref. Latour, 1987).

When it comes to the support from Krokan, heading the Department of Biotechnology, I do not have sufficient data regarding the process of enrolment: Did Børretzsen or other project members purposively enroll the new manager, was it the other way around, or was it perhaps a mutual process? In any case, it is evident that Krokan, looking for new projects, found that the omega-3 research fit well with his interests. So, when Hydro Innovation terminated the project support, Krokan had already become a strong ally.

Gulbrandsen, Krokan and project members with Børretsen taking the lead, aimed to recruit the Vice President who appeared as a relevant ally. They were supported by promising project results (*world-leading development of omega-3 fatty acids*). By proposing the idea of having a *complete chain* from fish farming, fish oil intended for nutrition supplement, to a therapeutic pharmaceutical, they tailored the project so that it catered to *his* explicit interests (*fish farming, fish feed*). In turn, the Vice President translated his interests to fit with the project members' interests (*continuation of the project*) by proposing the idea of *using commercial fish oil* (*making fish oil a new business area*). Likewise, the parties shared the idea of buying JC Martens (*prospective location for*

[540] The controversy outlined represents *one* of several instances where termination of the Omacor™ project was an issue. As such, the closure referred to was preliminary.

a manufacturing plant for k85/ a "flying start into the market"). The argument of a "flying start" served as an ally for the assistant director when trying to convince his superior of the idea of buying the company and enter into the fish oil industry.

Evidently, equipped with the series of human and non-human allies just outlined, supporters of the Omacor™ project managed to convince the corporate president and other corporate members of the viability of making fish oil a new business area. Thus, by enrolling a great number of new allies, project members succeeded in their efforts to obtain a new project owner.

Summing up, I conclude that the examples reviewed in this chapter show how Hydro personnel developed strategic alliances to succeed with critical challenges in the Omacor™ project. The examples illustrates that project members enrolled actors and actants by translating their interests to fit with the interests of the enrolled actors. As such, they managed to obtain necessary support to turn cases in favor of their own interests and points of view. [541]

12.6.4 Summary Discussion

Chapters 12.6.2 and 12.6.3 shed light on *how* and *why* people use and create networks in innovation projects. All together, they give a rich illustration of creativity as a social, collective achievement.

Broadly speaking, Chapter 12.6.2 points out that people in innovation projects, "problem owners", mobilize acquaintances in existing personal networks, or establish new contacts across organizational and disciplinary borders, to increase their capacity to accomplish complex project tasks they cannot pursue alone. In systems term, we may say innovators' main motivation behind network formations is to increase their capacity to achieve the purpose served by an innovation system.[542]

When it comes to the specific question of *how* people use and create networks, the case projects indicate that *people mobilize acquaintances in existing personal networks, or turn to professionals or organizations presumed to possess relevant expertise, resources, or power of influence*. For instance, the "Die Life" project shows that the subproject manager

[541] According to Latour (1987), the recruitment process (enrollment) represents the first of two necessary strategies to build a black box, that is, *recruitment* of alliances and *control* of alliances. My analysis sheds light on how people build alliances, but not on the second strategy aimed at keeping the interested groups in line. This is because I found it difficult to identify clear examples of how people built the interests into durable artifacts in the form of obligatory passage points in every-day practice.

[542] In the following, I use the term "innovator" as a collective term referring to companies or business units responsible for innovation projects (innovation project owners).

turned to his acquaintances at SINTEF Materials Technology when facing the die life problems. Similarly, the Omacor™ project illustrates that the professor at the University Hospital of North Norway turned to a former colleague concerning the double-blind “blood pressure” study. Furthermore, Harald Breivik, the project manager in the Omacor™ project, largely aimed to establish contacts with leading experts in the fields of pharmaceutical business and marine oils, that is, *new* contacts representing the *new* business area Hydro entered into. At the same time, he mobilized some of his new acquaintances in his personal network to solve particular problems. For instance, when facing opposition from US patent authorities, he contacted acquaintances at recognized institutions in the US and Canada since he knew that these world-leading researchers possessed a stronger power of influence than Norwegian professors.

Furthermore, the examples of how people use and create networks points out that recruitment of professionals to collaborative partnerships was based on individual *know-who* (Ref. Foray and Lundvall, 1996). However, where Foray and Lundvall (1996) apparently restrict *know-who* to include information about people with relevant knowledge, the example concerning the patent difficulties in the US suggests that complementary information on and attention to the status of professionals may be equally important. Accordingly, the current study complements the *Person* facet study (Chapter 8) by suggesting that *know-who* should include information about people with relevant knowledge *as well as* attention to and information about their power of influence in a specific context.

Concerning the question of *why* people use and create networks, access to critical expertise and necessary tangible resources recur as a main motive in the case projects. Clearly, the overall complexity and comprehensiveness of the case projects implied that vital innovation activities could not be accomplished by means of expertise and resources within one single department or business unit in Hydro. For instance, the accomplishment of work pertaining to the activities named “development of product and production process”, “manufacturing facilities”, and “patents” in the systems model of the Omacor™ project (Ref. Figure 12.2.1), required the joint efforts of specialists across disciplinary, departmental, and organizational borders. This was because the expertise and technology at the Analytical department was far from sufficient to accomplish the comprehensive tasks in question.

Moreover, the case projects illustrate that people establish professional networks to increase their capacity to deal with difficult problems. For instance, the project manager in the Omacor project established *community networks* consisting of experts sharing similar skills and expertise to learn *context-relevant skills* and facilitate information sharing and collective learning necessary to succeed with issues regarding methods of analysis. Similarly, subproject manager Rystad in the "Die Life" project formed *project networks* and *workshop networks* to deal with specific problems such as die design and temperature measurement.

Chapter 12.6.3 complements the findings referred to by showing that people in innovation projects use and create networks to support their interests and points of view regarding critical issues. People build *strategic alliances* by enrolling human and non-human actors in heterogeneous actor-networks. To enroll alliances, they often translate their interests to fit the interests of the enrolled actors (Ref. Latour, 1987).

So, to summarize, my case projects point out that access to necessary tangible resources, provision of critical competence, the power to influence critical issues, and encouragement of problem solving capacity were prominent motives for the use and creation of networks in innovation projects.

12.7 How Do Networks Influence Collective Creativity in Innovation Projects?

The study of how and why people use and create networks offers a sound basis for discussing the question of how networks influence collective creativity in innovation projects.

The finding that access to critical expertise was a driving force behind the creation of networks in the case projects brings the relationship between diversity of competence and collective creativity into focus once again. Chapters 9 and 12.5 shed light on the significance of diversity of competence, and I shall briefly repeat the main points here. Chapter 9 shows that diversity of competence is vital because requisite variety[543] of individual task-relevant skills is a necessary component of collective creativity.[544] The systems analysis of the Omacor™ project supports this finding by pointing out that innovation activities as a whole implies that the actors/organizations collectively possess the types and composition of competence demanded by the system's main function. If

[543] Ref. Morgan (1997);Nonaka and Takeuchi (1995)
[544] As discussed in Chapter 8, I define task-relevant skills as the combination of domain-relevant skills and context-relevant skills.

competence needed to accomplish one or more activities in an innovation system is scant, the development of the entire system will suffer. Moreover, Chapter 9 calls attention to that diversity of competence is important because it stimulates collective creativity-relevant skills, another component of collective creativity.[545] Accordingly, *networks may stimulate collective creativity by supporting collective task-relevant and creativity-relevant skills, two essential components of collective creativity.* As such, networks assist innovators in dealing with the complex, composite challenges posed by the purpose of the overall innovation activity (the main function of an innovation system, ref. Edquist, 1997; 2005).

Furthermore, my networks study shows that the acquisition of context-relevant skills and the encouragement of information sharing and collective reflections among members in community networks were other motives for network formations.[546] This observation partly overlaps, partly complements the former discussion on how networks influence collective creativity. First, membership in community networks enables beginners to learn context-relevant skills from experts in the field. Second, collective information sharing and collective reflection boost redundancy[547], which in turn increases collective context-relevant skills (e.g. knowledge of the situation regarding lack of official analysis methods and its implications in the Omacor™ project) (Ref. Chapter 9.4). Ergo, *networks may encourage collective creativity by boosting collective context-relevant skills, and thereby collective task-relevant skills.*

The finding that people form networks to get access to critical resources sheds further light on the significance of requisite variety. Similar to sufficient diversity of competence, requisite variety of tangible resources is a prerequisite for dealing with the complexity of innovation. Thus, networks composed of people/organizations with necessary competence as well as tangible resources (e.g. contract research organizations, pilot plant equipment, etc.) encourage creativity. Sufficient resources enable project members to involve themselves in a task and make the most of their task- and creativity-relevant skills.

Moreover, the findings regarding requisite variety of expertise and other resources implicitly call attention to the relationship between the allocation of resources and supervisory support. As discussed in Chapter 9.2, supervisory support is a prerequisite for the allocation of sufficient resources, including resources needed to hire specialists across

[545] As discussed in Chapter 5.3, creativity-relevant skills are skills stimulating the creation of appropriate novelty (Ref. Amabile, 1983a/b; 1988)
[546] Context-relevant skills include relevant knowledge of the problem context and technical skills required and are a part of task-relevant skills (Ref. Chapter 8).
[547] Ref. Morgan (1997); Nonaka and Takeuchi (1995)

departmental and organizational borders. In this connection, my network study shows that networks in terms of heterogeneous actor-networks provide innovators with the power to determine the outcome of controversies regarding allocation of resources. For instance, if members of the Omacor™ project had not successfully mobilized support from corporate management and managers in the Agriculture division, the project could easily have been terminated due to lack of financial support. Thus, my study illustrates that networks may influence collective creativity through ensuring requisite variety of resources in two complementary ways: First, networks may enable access to financial resources required to establish project networks in the first place. Second, once sufficient financial resources are provided, networks may stimulate collective creativity by embodying the requisite variety needed to create and implement innovations.

The Omacor™ project suggests that the political dimension should play a prominent part in discussions about networks and collective creativity. Innovators' capacity to create networks that have a significant influence on critical issues may be decisive for the innovators' capacity to accomplish difficult project tasks. For instance, if the Hydro personnel had not succeeded in creating an effective network of specialists and "proofs", they would not have managed to obtain patent approval in the US, or having the Dyerberg patent declared null and void. A critical component in the innovation system (patents) would then have suffered, making commercial success difficult. Thus, the Omacor™ project shows that strategic alliances in the form of heterogeneous actor-networks increase innovators' capacity to accomplish difficult tasks because they give innovators' the necessary power to determine the outcome of controversies regarding the new technology.

The Omacor™ project also illustrates that informal personal networks may influence collective creativity in the same way as actor-networks. Chapter 12.6.2 calls attention to that project manager Breivik's emphasis on establishing relevant networks provided himself with considerable power of influence by means of social capital. For instance, if it were not for his social capital, Hydro would probably not have managed to gain ground regarding the controversy surrounding Hydro researchers' methods of analysis for omega-3 concentrates. Thus, also individual personal networks, representing social capital, embody the potential to give innovators the necessary power to turn cases in favor of their own interests and points of view. So, my network study points out that various types of networks may support collective creativity by giving innovators the power to influence critical issues of vital importance for innovation success.

To summarize, my study shows that various types of networks such as project networks, community networks, informal personal networks, and heterogeneous actor-networks play a significant role in innovation projects, enhancing innovators' capacity to deal with the composite, complex challenges posed by an innovation system. Networks influence collective creativity by offering problem owners the opportunity to learn necessary context-relevant skills, by giving problem owners the power to influence struggles in their favor, and by boosting collective task-relevant and creativity-relevant skills, two major components of collective creativity.

Still, the *Person* facet analysis in Chapter 8 reminds us that the very formation of effective networks depends on the contributions from individuals with high interpersonal skills. Likewise, the *Press* facet analysis in Chapter 9 points up that the very organization of the network collaboration (e.g. work forms) also influence how networks stimulate collective creativity. Accordingly, in order to fully understand how networks influence creativity, it is important to take several facets of innovation and creativity into account.

Part IV: Conclusion

In this part of the thesis I present the conclusion of the study. Chapter 13 gives a summary of the central findings in light of the thesis' research questions. I start with a brief recapitulation of the main purpose of the thesis (Chapter 13.1). Then I give an outline of the central findings derived from the facet-specific analyses and discussions in Part III of the thesis (Chapter 13.2). This outline is followed by a summary of central findings in the sense of a list of organizational conditions for innovation (Chapter 13.3). Finally, Chapter 13.4 presents the thesis' contributions to the literature, while Chapter 13.5 provides suggestions for further research.

Chapter 13 Central Findings

13.1 Introduction

This thesis highlights organizational conditions for innovation based on retrospective case studies of research projects in Hydro. The point of departure was the request to focus on how Hydro could reduce the traditional emphasis on stepwise process improvements and stage for a larger degree of radical innovations. A thorough conceptual study made me conclude that ”radical innovation” was subject to great ambiguity, leading up to the conclusion that it was uncertain whether any of the case projects would be regarded as cases of “radical” innovation *at all*. This contributed to the decision to drop the explicit attention to “radical” innovation, broadening the focus to “innovation”. Against this background, I stated that the objective of this thesis was to gain new knowledge of organizational conditions for innovation through retrospective case studies of research projects. I then posed the following main research question:

> *What are organizational conditions for innovation?*

Most innovation research represents mono-disciplinary studies of one or two facets of innovation. The core argument in this thesis is that innovation is a multifaceted phenomenon that is too complex to be studied from a single disciplinary perspective.
In the beginning of this thesis I therefore advocated a multiperspective approach, emphasizing the importance of using perspectives and theories from several disciplines. Based on the conceptual discussions in Chapters 2 through 4 I created a model for studying innovation as a multifaceted phenomenon consisting of five facets previously (for the most part) studied independently: *Person*, *Press*, *Product*, *Process*, and *Partnership*. In Chapter 5 I then used the theoretical reviews and discussions as the point of departure for developing the main research question into the following facet-specific sub-questions:

Person facet:

What are salient characteristics of individual contributions promoting innovation?

Press facet:

How do supervisory encouragement and organizational support promote collective creativity in innovation projects?

How does diversity in competence promote collective creativity in innovation projects?

What approaches and work forms increase the likelihood for innovation success?

Product facet:

How do project members perceive the outcome of the projects in light of the concepts incremental and radical innovation?

Process facet:

Is the need for creativity most prominent in the early period of innovation processes?

How do "innovative" ideas emerge and unfold over time?

How do people collectively create new knowledge in innovation projects?

Partnership facet:

Which types and compositions of competence are important to succeed with innovation?

Which activities by which actors/organizations are important to succeed with innovation?

Which institutional rules influence the activities of the actors/organizations in carrying out activities in innovation projects?

How do networks influence collective creativity in innovation projects?

How and why do people use and create networks in innovation projects?

13.2 Central Findings

This chapter presents a brief summary of the central findings derived from the facet-specific analyses and discussions presented in Chapters 8 through 12. The summary outlines the findings pertaining to the main facet-specific research questions only.

Person Facet:

Salient Characteristics of Individual Contributions Promoting Innovation

The study of individual contributions in the case projects calls attention to the following three salient characteristics: *Domain-relevant skills, context-relevant skills,* and *interpersonal skills*. Domain-relevant skills are disciplinary knowledge and skills in the field of study, or domain, in which one has been trained. The finding that such skills promote innovation is in line with existing research (Ref. Chapter 5.3.3). However, as opposed to prominent perspectives on individual creativity (e.g. Amabile, 1983a/b; 1988; Csikszentmihalyi, 1999; 2001), the study shows that domain-relevant skills constitute a necessary but not sufficient component of individual creativity: To promote innovation, experts must also have context-relevant skills, i.e. relevant knowledge of the problem context and required technical skills. Thus, I conclude that *task-relevant skills*, covering domain-relevant skills and context-relevant skills, constitute the expertise component of individual creativity.

Furthermore, the study shows that interpersonal skills such as *political skills, communication skills, power by virtue of social capital, power by virtue of formal authority, social skill, empathy, and know-who* are vital for individual as well as for collective creativity. Interpersonal skills enable the obtainment of critical support from significant others, encourage the development of context-relevant skills, make access to important tangible resources easier, provide access to necessary expertise, and encourage a well-functioning interplay of people in innovation projects by facilitating adequate collective learning processes. The finding regarding interpersonal skills forms a contrast to most creativity research that implicitly assumes that creative individuals operate in a vacuum in which interpersonal skills are not relevant. Thus, the study of individual contributions illustrates that individual task-relevant and interpersonal skills are essential components of individual creativity and consequently vital for innovation.

Press Facet:

Supervisory Encouragement and Organizational Support

The study of encouragement and support in the case projects points out that supervisory encouragement and organizational support promote collective creativity in several ways. First, organizational support and supervisory encouragement in the sense of access to critical resources stimulate all components of creativity, i.e. task-relevant skills, creativity-relevant skills, interpersonal skills, and task motivation. This is because access to critical resources acts as an extrinsic synergistic motivator increasing task involvement and enables people to make the most of their expertise. Second, organizational support and supervisory encouragement stimulate intrinsic motivation and team spirit by heightening project members' sense of importance/urgency in the work. Third, supervisory encouragement in terms of provision of autonomy boosts intrinsic motivation by increasing project members' sense of self-determination. In addition, autonomy has a direct positive influence on the non-motivational components of creativity by allowing people to approach problems in ways that make the most of their overall skills and expertise. As such, it may also promote serendipity and other antecedent factors such as diversity and redundancy. The beneficial impact of autonomy on collective creativity presupposes a mutual supervisor-subordinate trust.

The findings regarding encouragement and support follow existing research on antecedents of creativity (Ref. Amabile, 2001). At the same time, they offer new insight into how organizational support and supervisory encouragement promote creativity at the collective level. As such, my study points out that supervisory encouragement and organizational support are essential conditions for innovation.

Diversity of Competence

The study of diversity of competence in the case projects illustrates that diversity of competence promotes collective creativity by supporting collective task-relevant and creativity-relevant skills, two necessary components of collective creativity. Diversity of competence implies sufficient variety of both academic competence and practical expertise. Moreover, the study also indicates that collective creativity-relevant skills enabled by such diversity represent a distinct collective quality; they embody a group phenomenon that is qualitatively different from the sum of individual creativity-relevant skills. Moreover, I find that diversity has a direct impact on task-relevant and creativity-relevant skills. In this way, the study supplements previous research by showing that diversity, at least at the collective level, has a direct impact on the non-motivational components of creativity.

The findings regarding diversity of competence are in line with existing research (Ref. Nonaka and Takeuchi, 1995; Amabile, 2001). At the same time, they provide a solid empirical illustration of how diversity promotes collective creativity. I conclude that diversity of competence is a major condition for innovation.

Approaches and Work Forms

The study of approaches and work forms in the case projects shows that approaches and work forms supporting co-generative learning and a collective reflective practice increase the likelihood of innovation success. This implies the creation of appropriate arenas for communication (social fields of interaction). Such arenas allow socialization and communicative actions to take place among experts representing a great variety of competence. In particular, they boost the creation of redundant context-relevant skills, an essential component of collective creativity. The study shows that the following arenas are particularly useful: *face-to-face meetings and stays in the problem context*, *workshops, joint verification-/validation efforts*, and *informal master-apprentice dyads* enabled by visits to relevant expert groups. In addition, *pre-projects* aimed at thorough co-generative problem definition and *parallel processing* are fruitful strategies. Parallel processing boosts repeated cycles of collective reflection and action, thereby speeding up the overall progress of project efforts. So, I conclude that the orchestration of work forms and approaches that stimulate co-generative learning and a collective reflective practice is an important condition for innovation.

Product Facet:

Perceptions of the Outcome of Innovation Projects in Light of the Concepts Incremental and Radical Innovation

The study of individual perceptions shows that subjective assessments express considerable disagreement in light of the concepts incremental and radical innovation. A specific project result may be regarded as ”incremental”, ”partly incremental/partly radical”, or ”radical” dependent on what referential material individuals call upon when making their judgment. Individuals differ in their use of judgment criteria, frames of reference, and attention to factors such as the nature of the process, characteristics of the innovation (outcome of process), and impact of the innovation (outcome of process). To some extent, people who agree on the “radicality” of a specific object propose similar reasoning. At the same time, agreement may also reflect quite different foci. Accordingly, the study clearly demonstrates that the innovation labels ”incremental” and ”radical” are subject to extensive interpretative flexibility (Ref. Pinch and Bijker, 1987). This finding represents a striking contrast to most innovation studies that are based on the assumption that individual assessments of innovativeness reflect unified agreement (Ref. King and Anderson, 1990).

Classification of innovation is regarded as essential for effective innovation management since different kinds of innovation require different management approaches. As such, the study suggests that collective reflection on relevant concepts is a condition for innovation. Without such debates, innovation labels can hardly be of any use when it comes to effective innovation management.

Process Facet:

The Need for Creativity in the Beginning versus Later Periods of Innovation Projects

The analysis and discussion of the data in light of the *Process* facet clearly points out that innovation calls for creativity throughout the entire process. First, the analysis of how innovative ideas emerge and unfold over time shows that innovation is a collective improvisatory process driven by the participants’ improvisation on an open-ended innovative idea. The process is characterized by recurrent cycles of idea generation and idea selection, demonstrating that innovation is not a linear process wherein the need for idea generation is most prominent in the beginning. This finding demonstrates that the traditional sequential creativity-innovation model is not adequate. The analysis of how people collectively create knowledge in innovation projects sheds further light on this finding by illustrating that the unpredictable, uncontrollable nature of innovation processes requires regular framing and reframing of problems (e.g. innovative ideas). The project participants’ joint improvisation on the innovative idea implies a recurrent need for exploring open-ended Which/How/What-questions, and this investigation, in turn, aims at creating solutions to these problems, and so on in an ongoing flow of inquiry. This underlying non-linear divergent-convergent system dynamics clearly indicates that the need for creativity in terms of the capacity to define and solve open-ended problems in a novel, appropriate way is not most important in the early period of innovation processes. Thus, I conclude that *the need for creativity is not most prominent in the early period of innovation processes*.

The finding that innovation calls for creativity throughout the entire innovation journey is important. By demonstrating that the traditional linear model of innovation is not adequate, it challenges the prevailing assumption that innovation success primarily depends on the ability to identify creative people with creative ideas. Indeed, individual creativity is important (Ref. Chapter 8). However, the study of the *Process* facet of innovation and creativity suggests that the project participants' *collective* capacity to improvise and keep inquiry moving throughout the unpredictable, uncontrollable innovation journey is a more significant criterion of success. As such, the orchestration of a continuous, fruitful interplay of participants seems to be a major condition for innovation.

Partnership Facet:

Types and Composition of Competence

The systems analysis of the Omacor™ project demonstrates that innovation is a collective open-ended activity implying the involvement of a great many specialists who collectively represent a large variety of expertise. The types and compositions of competence needed to succeed with innovation are context-specific, depending on the main function of the innovation system. *To ensure requisite variety of expertise, the overall competence possessed by involved actors/organizations must match the complexity of the innovation system*. This finding reflects two essential points: First, innovation success implies the involvement of relevant competence in *all parts* of the system. Relevant competence means *task-relevant skills* covering domain-relevant skills and context-relevant skills in terms of relevant systems specific knowledge. In this connection, business or trade knowledge appears as a vital component of managerial competence. Second, the expertise needed to deal with the "commercial challenge", often labelled "commercialization" or "implementation", is no less important than competence required to "create and develop" new products or processes. As such, my study also indicates that creativity is needed in all parts of the innovation system; innovation is not a matter of heuristic "technological" tasks and algorithmic "commercial" tasks, as several existing innovation models seemingly suggest (Ref. Chapter 4). So, I conclude that requisite variety of "technological" and "commercial" task-relevant skills is a major condition for innovation.

Networks and Collective Creativity

My study of networks in the case projects provides a solid illustration of creativity as a social, collective capacity. It illustrates that various types of networks such as project networks, community networks, informal personal networks, and heterogeneous actor-networks play a significant role in innovation projects, enhancing innovators' capacity to deal with the composite, complex challenges posed by an innovation system. Networks influence collective creativity by offering problem owners the opportunity to learn necessary context-relevant skills, by giving problem owners the power to influence struggles in their favor, and by boosting collective task-relevant and creativity-relevant skills, two major components of collective creativity. Thus, my study of how networks influence collective creativity points out that interdisciplinary, cross-organizational networks of specialists are vital for innovation.

To summarize, the current overview of findings shows that each facet of the 5P diamond model contributes important, yet insufficient knowledge of innovation. To get a comprehensive understanding of organizational conditions for innovation, all facets must be taken into account.

13.3 Organizational Conditions for Innovation

The facet-specific findings summarized in Chapter 13.2 contribute to a comprehensive understanding of innovation. The findings support and complement each other, calling attention to major organizational conditions for innovation. In essence, they teach us that *creativity is the basic condition for innovation*. The *Person* and *Partnership* facet studies demonstrate that individual creativity is a necessary, but not sufficient condition for innovation: Innovation is contingent on both individual and collective creativity. The *Process* facet study complements this finding by showing that innovation calls for creativity during the entire process. Likewise, the *Partnership* facet study illustrates that creativity is a prerequisite for both creation and implementation of innovations. As such, *organizational conditions for innovation mean conditions promoting the individual and collective capacity to continuously deal with pertinent open-ended problems in innovation* *projects*. Altogether, my findings point out the following organizational conditions for innovation:[548]

Individual Creativity (Individual Task-Relevant Skills, Creativity-Relevant skills, Interpersonal Skills, and Task Motivation)

Task-relevant skills include domain-relevant skills and context-relevant skills. Domain-relevant skills are disciplinary knowledge and skills, that is, knowledge of the field of study in which one has been trained. *Context-relevant skills* cover relevant knowledge of the problem context and required technical skills. *Creativity-relevant skills* cover skills stimulating the generation of novel ideas. Interpersonal skills are skills relating to the relationship between people, such as *political skills, communication skills, power by virtue of social capital, power by virtue of formal authority, social skill, empathy, and know-who. Task motivation* is the motivation to engage in a task. Altogether, task motivation and the three types of skills are the essential components of individual creativity.

Requisite Variety of Task-Relevant Skills

Innovation depends on the involvement of specialists who collectively possess requisite variety of task-relevant skills, i.e. domain-relevant skills and context-relevant skills. Such diversity means requisite variety of task-relevant skills pertaining to both “technological” and “commercial” issues, including academic competence as well as practical expertise.

Organizational Support and Supervisory Encouragement

Supervisory encouragement and organizational support stimulate intrinsic task motivation and team spirit, enable *autonomy*, and facilitate the provision of critical *resources*. As such, both individual and collective creativity is stimulated.

Autonomy

Autonomy in the sense of freedom of how to reach project goals boosts intrinsic motivation by increasing project members’ sense of self-determination. In addition, autonomy has a direct positive influence on task-relevant skills, creativity-relevant skills, and interpersonal

[548] Clearly, the organizational conditions to be presented are not separate, but tightly interwoven conditions. Some serve as conditions for other conditions, which in turn are circumstances indispensable to still other conditions. For instance, individual interpersonal skills are a condition for the creation of *networks*, which in turn facilitate *diversity of competence* and *resources*. *Resources*, in turn, are also dependent on *organizational support*, and so on. Accordingly, attempts to present the organizational conditions in a way that fully accounts for the interrelationships would soon become to complex. Therefore, the coming list simply provides a brief overview of essential organizational conditions only.

skills by allowing people to approach problems in ways that make the most of their overall skills and expertise. The beneficial impact of autonomy on collective creativity presupposes *mutual supervisor-subordinate trust*.

Mutual Subordinate-Superior Trust

Mutual trust is the hallmark of a creativity-supportive work climate, serving as the lifeblood for encouragement of task motivation and team spirit. Freedom of process presupposes that innovation managers have faith in their co-workers. Still, trust is about more than granting autonomy. The beneficial effect of autonomy is undermined if project members do not have confidence in supervisors' commitment to the project.

Resources

Access to critical resources make people make the most of their expertise and encourage task motivation. As such, resources stimulate all components of creativity, i.e. task-relevant skills, creativity-relevant skills, task motivation, and interpersonal skills.

Networks

Various types of networks such as project networks, community networks, informal personal networks, and heterogeneous actor-networks influence collective creativity by offering problem owners the opportunity to learn necessary context-relevant skills, by giving problem owners the power to influence struggles in their favor, and by boosting collective task-relevant and creativity-relevant skills, two essential components of collective creativity.

Power to Influence Critical Issues

The accomplishment of critical innovation tasks often implies that innovators must have the power to influence issues in their favor. Individual interpersonal skills such as political skills, power by virtue of social capital, and power by virtue of formal authority are important. Similarly, networks in the sense of social capital and strategic alliances are vital sources of power.

Work-Forms Stimulating Co-Generative Learning and a Collective Reflective Practice

Approaches and work forms supporting co-generative learning and a collective reflective practice increase the likelihood of innovation success. In particular, such strategies boost the creation of redundant context-relevant skills, an essential component of collective creativity. They depend on appropriate arenas for communication, such as *face-to-face meetings and stays in the problem context, workshops, joint verification-/validation efforts, and informal master-apprentice dyads enabled by visits to relevant expert groups*. In addition, *pre-projects* aimed at co-generative problem definition and *parallel processing* are fruitful strategies.

Co-Generative Problem Definition

Since innovation is an open-ended activity, emphasis on problem definition is important. In this connection, co-generative problem definition is a major factor of success. Co-generative problem definition permits the development of a mutually agreed-upon problem focus that, in turn, facilitates the creation of commitment to an innovation project. In addition, it allows all participants to make the most of their expertise and make “outsiders” acquire vital context-relevant skills.

Collective Reflection on Relevant Innovation Labels

Classification of innovation is essential for innovation since different kinds of innovation require different management approaches. However, concepts such as ”incremental” and ”radical” innovation are subject to extensive interpretative flexibility. No open-ended tasks can be successfully managed without emphasis on problem definition. This applies to open-ended tasks of becoming “innovative” or aiming to stage for “radical” product innovations as well. Accordingly, collective reflections and explicit debates concerning definition and classification criteria for concepts such as “innovation” and “radical” innovation are important.

13.4 Contributions to the Literature

This chapter highlights how this thesis contributes to the existing literature. A major argument in this thesis is that a satisfactory understanding of innovation implies attention to creativity. For this reason, the main bodies of literature have been literature on innovation and creativity. The intention has been to bridge conceptual and disciplinary gaps in order to gain better insight into organizational conditions for innovation. As such, this thesis contributes to the existing literature on both innovation and creativity.

Most innovation research represents mono-disciplinary studies of one or two facets of innovation. Such approaches tend to result in a simplistic, unsatisfying view of innovation because a part of the phenomenon is viewed as the whole phenomenon. In contrast, this thesis offers a multiperspective approach and a conceptual framework that contribute to a comprehensive understanding of innovation. The 5P diamond model of innovation and creativity conceptualizes innovation as a multifaceted phenomenon composed of five facets that (for the most part) have been studied independently. As such, it stands out as a potentially powerful, innovative conceptual framework capable of overcoming the limitations of traditional creativity and innovation research.

The multiperspective approach and the 5P diamond model constitute the thesis' major theoretical contribution to the literature on innovation and creativity. Another important contribution concerns the conceptualization of innovation and creativity and the relationship between these phenomena.

Similar to most literature on innovation, this thesis regards creativity as a prerequisite for innovation. At the same time, it confronts three widespread perspectives on creativity, claiming that these fail to recognize innovation as a complex, open-ended activity requiring continuous co-creation of knowledge in interdisciplinary, cross-organizational networks. First, where most theories define creativity as idea generation (Ref. Chapters 3.3.1 and 4.2.3), this thesis defines creativity as the capacity to define and solve open-ended problems. Second, where most perspectives of innovation view creativity as the very source of innovation, i.e. the point of departure for the innovation journey (Ref. Chapter 4.2.7), this thesis asserts that creativity is needed throughout the entire innovation process. Third, where existing literature tends to portray creativity solely as an individual quality (Ref. Chapters 3.3. and 4.2.2), this thesis states that creativity is *both* an individual and a collective capacity. In this connection, the very definition of innovation and creativity as an activity and capacity respectively, provides a reasonable and innovative way to distinguish between these phenomena. In contrast to existing distinctions, this distinction cuts across narrow and incomplete dichotomies and attention to linear conceptualizations of innovation (Ref. Chapter 4).

Furthermore, this thesis also provides empirical findings that represent valuable contributions to the literature.

First, the finding that interpersonal skills were a salient characteristic of individual contributions promoting innovation is a corrective to most creativity research that reflects the mistaken belief that interpersonal skills are fully irrelevant to individual creative performance (Ref. Chapter 5.3.6). More specifically, the study provides a corrective by virtue of illustrating how various types of interpersonal skills influence creativity.

Second, the finding that context-relevant skills are vital calls attention to that existing perspectives of individual creativity seem to ignore that individuals often operate within complex problem contexts reaching beyond the domain in which they have been trained (e.g. Amabile, 1983a/b; 1988; Csikszentmihalyi, 1999; 2001). As such, these perspectives are not sufficiently adequate for understanding individual creativity in complex-real life settings such as innovation projects. Accordingly, the extension of Amabile's componential framework into a four-componential model including task-relevant skills, creativity-relevant skills, task-motivation, and interpersonal skills appears as a useful contribution to the literature (Ref. Chapter 8).

Third, the finding that innovation calls for ongoing creativity challenges prevailing assumptions about creativity in the literature on innovation and creativity. A majority of innovation researchers now reject the linear model of innovation (Rosenberg, 1991). Still, my conceptual study shows that most theories on innovation - including conceptualizations of the relationship between creativity and innovation – implicitly portray innovation as a linear process triggered by creativity in terms of the creation of a novel, appropriate idea (Ref. Chapter 4). Not only do these theories reflect the assumption that the need for creativity is most prominent in the early periods of an innovation process, they also give the impression that the *implementation* of ideas (or products) does not require creativity; implementation is "hard work" only. In contrast, this thesis illustrates that innovation is not a linear process in which an initial idea creation phase results in an "innovative" idea that is further developed and implemented in subsequent phases. Rather, innovation is an emergent, dynamic process in which idea creation, idea development, and idea selection are intertwined activities in an ongoing flow of inquiry. Likewise, this thesis shows that creativity is a prerequisite for both "creation" and "implementation" activities. Innovation is not about open-ended (heuristic) "technological" tasks and simple algorithmic "commercial" tasks. Accordingly, the findings surrounding creativity in innovation projects represent a valuable contribution to the literature.

Fourth, the finding that innovation is a collective improvisatory process contributes to new insight into how people collaborate and interact to create and implement new products and processes in a highly ambiguous, uncertain, complex, and uncontrollable context. This is important since our understanding of how knowledge and innovation operate at the organizational level is fragmented (Ref. Fagerberg, 2005).

Fifth, the finding that subjective judgments of innovativeness in light of the incremental-radical continuum differ to a large extent provides a useful corrective to the prevailing assumption of unified agreement found in the literature (Ref. King and Anderson, 1990).

13.5 Suggestions for Further Research

This thesis is based on a retrospective study of four research projects in a large industrial company. In a strict sense, the case projects are R&D projects, representing *one* innovation activity only. At the same time, they reflect emphasis on the intentional creation and implementation of new, appropriate products/processes hoping to create economic benefit and other values. Therefore, I argue that the four R&D projects serve as examples of innovation projects.

Most of the empirical data, however, concerns research activities, and in particular work related to the creation and development of new, appropriate technological products or processes. I have some data on implementation activities and factors necessary to succeed with this aspect of innovation. It suggests that implementation/commercialization of research results often fail, or are not paid sufficient attention to. According to people in Hydro Aluminium Extrusion, the emphasis on implementing research results has often been neglected within this business sector. This tendency led up to the designation of 2002 as the “Year of Implementation,” and the aim of an implementation rate higher than 40 percent. Moreover, in order to stimulate implementation, new research projects were to be followed by specific implementation projects. I have no data on the effect of these actions. Still, the case study data from the PROSMAT Extrusion projects indicates that the very conceptualization of innovation as a linear process where the creation and implementation of new, appropriate knowledge are separate sequential processes may be one explanation for the difficulties concerning implementation. Accordingly, it would be interesting to do further research on how industrial companies think of implementation, and on the practical implications of these ideas. Such research would contribute to a better understanding of how innovation can be conceptualized, organized, and managed in order to increase the likelihood of success, that is, the likelihood of R&D activities actually creating significant economic benefit and other values. One possible research approach is retrospective case studies. Still, I suppose that real-time studies of for example HAEX's R&D projects and their subsequent "implementation" projects would be a better strategy. Such approaches allow researchers to study "innovation in the making" (Ref. Darsø, 2001) and facilitate the acquisition of important context-relevant skills in a way that retrospective studies cannot provide.

Another research topic deserving further attention is the relationship between individual and collective interpersonal skills. In this thesis I demonstrate that individual interpersonal skills constitute an essential part of individual creativity. I assume that collective creativity reflects individual interpersonal skills as well as interpersonal skills of a specific collective quality. Yet, I have no clear data on "collective interpersonal skills". Nor does the literature reviewed in this thesis provide sound, explicit discussions on the matter. Therefore, it would be interesting to conduct a further investigation into questions such as: What is the relationship between individual interpersonal skills and the project members' capacity to play well together? Is the collective capacity to play together the sum of individual interpersonal skills – or does it reflect individual interpersonal skills acting in concert with distinct collective interpersonal characteristics that are qualitatively different from individual skills? In this connection, real-time interdisciplinary studies into the interaction of members of innovation teams appear to be a relevant research approach.

A third suggestion for further research concerns the concept of improvisation. In this thesis I have shown that literature on improvisation in jazz and drama provides powerful concepts for explaining how people create new knowledge in highly ambiguous, uncertain, complex, and uncontrollable contexts. Hence, the study provides further evidence for the importance of research on improvisation, as previously emphasized by, among others, Alterhaug (2000) and Jørgensen (2004). Likewise, the finding that innovation is about collective improvisation indicates that attention to, and the practice of, improvisation skills may be a fruitful way to stimulate creativity in general. For this reason, studies of how organizations can nurture improvisation would be of great value. Research on programs such as "Improvisation – a key to creativity and innovation" proposed by Oddane and Lysklett (2003) appears to be one appropriate strategy here.

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Appendix A: Glossary Aluminum Extrusion[549]

Alloy: Material that has metallic properties and which is composed of two or more chemical elements, one always being metal. The alloy's properties are usually different from those of the components.

Bearing: The depth of the extruding aperture, at right angles to the die face, which controls metal flow and to some extent speed of flow; the surface along which the aluminum flows and is shaped.

Billet: A solid semi-finished round, square or rectangular cast bar produced in different diameters, sizes and lengths for use in the extrusion process.

Container: A steel cylinder, usually fitted with a removable liner having an inside diameter slightly larger than the billet to be extruded.

Deflection: Distortion or bending of the die. Insufficient support of die will cause it to deflect, lessening the effectiveness of the bearing; also termed *dishing*, *caving*, and/or *sagging*.

Die: Unit of press tooling with one or more machined openings to product the desired extruded section or sections.

Die corrector: A person responsible for quality assessments, correction and maintenance of dies during test runs and ordinary production; works in the **die shop** in the press plant

Die designer: A person who designs dies; part of the die manufacturing plant staff

Extrusion: Shaping of aluminum sections by forcing cylindrical billets through a die

Extrudate: See **Profile**

[549] This glossary is largely based on the Aluminium Extrusion Glossary found at http://www.alumaxbath.com/tech/ag.htm 04- 08- 04

Metal Flow: The manner in which metal moves both in the container and through the extrusion die.

Profile: (synonymous with section and extrudate) – the product made by sectioning extrusions

Profile designer: Person who makes a profile/section design

Section – see **profile**

Taper Heating: The staged or gradient application of heat through induction coils. Thermal differential between billet ends offsets the frictional and other heat generated during the extrusion cycle so that metal temperature at the die is constant. Under careful handling billet end may be quenched in water after heating to provide for a similar heat gradient.

Appendix B: Glossary Pharmaceutical Product Development

Chemical/Pharmaceutical file: The documentation of the development and manufacturing of a new therapeutic pharmaceutical (in accordance with **GMP**) required for application for marketing authorization for a new therapeutic pharmaceutical (approval for an indication).

Clinical File: The documentation of clinical studies (in accordance with **GCP**) required for the application of marketing authorization for a new therapeutic pharmaceutical (approval for an indication).

Clinical Studies: Studies using people with the disease(s) to determine if a therapeutic pharmaceutical is, in fact, effective.

Phase 1 Studies

Short-term safety and efficacy studies in healthy humans, providing the basis for subsequent studies on people with the disease(s) or risk factors.

Phase 2 Studies

Studies involve a small number of people with the disease(s) or risk factors.

Phase 3 Studies

Large long-term studies involving a great number of people with the disease(s) or risk factors. For instance, the GISSI-Prevention Study, representing the "medical breakthrough of OMACOR™, included 11 324 patients during 3 1/2 years.

Phase 4 Studies

Clinical studies concerning approved products. These studies may focus on particular patient groups, dosages, interactions etc.

Double-Blinded Study: A study in which at least two separate groups receive the experimental medication or procedure at different times, with neither group being made aware of when the experimental treatment or procedure has been given. Double-blinded studies are often chosen when a treatment shows particular promise and the illness involved is serious. It can be hard to recruit human subjects for a blinded study of a promising treatment when one group will receive only a placebo or an existing medicine.

Good Clinical Practice (GCP): Directions for the conduct of clinical studies defined by national or supranational regulatory authorities such as the Food and Drug Administration in the USE and The European Agency for the Evaluation of Medicinal Products (EMEA) in Europe.

Good Laboratory Practice (GLP): Directions for the conduct of pre-clinical (pharmacological/toxicological studies) laboratory studies defined by national or supranational regulatory authorities such as the Food and Drug Administration in the USE and The European Agency for the Evaluation of Medicinal Products (EMEA) in Europe.

Good Manufacturing Practice (GMP): Manufacturing quality standard for therapeutic pharmaceuticals and medical devises defined by national or supranational regulatory authorities such as the Food and Drug Administration in the USE and The European Agency for the Evaluation of Medicinal Products (EMEA) in Europe.

Hypertriglyceridaemia: Hypertriglyceridaemia refers to a state of an elevated level of triglycerides (fatty components) in the blood.

Indication: The disease(s) for which a therapeutic pharmaceutical is used.

Marketing Authorization: Approval of a new therapeutic pharmaceutical for an indication. The approval means that the company can include the information in their package insert (product label) regarding the use of the drug for that indication. The manufacturer is allowed to sell and market the product within the approving country. The manufacturer can claim that the drug is effective for the approved indication and use this information to market their drug to patients and physicians[550]. Manufacturers are not allowed to market their drugs for indications that have not been approved by regulatory authority.

MI: An abbreviation for myocardial infarction, commonly known as “heart attack”.

Off-Label Indication (Applies to the US only): Once a drug has been approved by the FDA for an indication and then marketed for that indication, physicians are allowed to prescribe the drug for any other indication if there is reasonable scientific evidence that the drug is effective for that indication. These uses that have not been approved by the FDA are the off-label indications.

Pharmacological Studies: Studies aimed at identifying potential effects of a substance.

Pharmacology/Toxicology File: The documentation of pre-clinical studies (in accordance with GLP) required for the application of marketing authorization for a new therapeutic pharmaceutical (approval for an indication).

Post-MI Patients: Patients who have had a myocardial infarction (“heart attack”).

Pre-Clinical Studies: Pre-clinical studies, covering pharmacological and toxicological studies, are studies on animals or cell substances aimed at testing aspects of safety and efficacy of chemical substances. Such studies, which have to be performed in accordance with the directions of Good Laboratory Practice (GLP), are a prerequisite for subsequent studies on human beings.

Secondary Prevention in Post-MI Patients: Prevention of mortality for patients who have had a myorcardial infarction (“heart attack”)

[550] http://www.medicinenet.com 2006-05-02

Toxicological Studies: Studies focused on safety topics. The purpose of these tests is to see if the substance has some unexpected surprising effects.

Third-Party Reimbursement System: Many therapeutic pharmaceuticals or biomedical devices cost a lot more than most people are able to pay for. As a consequence, national or medical security systems attempt to compensate for this through third-party systems of reimbursement.

Appendix C: Overview of Field Activities

Time period	Description activity	# of interviews /conver-sations	# taped	# Transcribed	# of tran-scribed A4 pages	Type of data
February 2000 2000-02-10 2000-02-23	Conversation with one of the members of *The Birkeland Award* Jury (Trondheim) Conversation with head of Norsk Hydro Corporate R&D staff (Oslo)	2				Field notes
April-May 2000 2000-04-27 2000-05-05 2000-05-19	Conversations with: Research Director, The Norsk Hydro R&D Center, Bergen (Oslo) Research Director, Hydro Aluminium R&D Center, Karmøy, (Karmøy) Research Director, The Norsk Hydro Research Center, Porsgrunn, (Porsgrunn)	3				Field notes
October-November 2000 2000-06-10	Telephone conversation with Research Director, HA R&D Center, Karmøy	5				Field notes

Time period	Description activity	# of interviews /conver-sations	# taped	# transcribed	# of tran-scribed A4 pages	Type of data
2000-11-07 2000-11-08 2000-11-17	Conversations/ Introductory meeting with members of the Omacor™ project, members of the MTO project, and the personnel consultant at the Norsk Hydro Research Center, Porsgrunn (Porsgrunn) Conversation with MTO -researchers (Porsgrunn) Conversation with Omacor™-researchers (Porsgrunn) ------------------- Conversation with Research Director, HA R&D Center, Karmøy, and project manager PROSMAT Extrusion (Karmøy)					
August 2001 2001-08-29-2001-08-31	Interview with personnel manager, The Norsk Hydro Research Center, Porsgrunn (Porsgrunn) Interviews with participants in the Omacor™ project Document review	3	2	2	49	Field notes Tapes Tran-scripts

Time period	Description activity	# of interviews /conver-sations	# taped	# transcribed	# of tran-scribed A4 pages	Type of data
2001-08-29- 2001-08-31	Guided tour The Norsk Hydro industrial park, (Porsgrunn)					
October 2001 2001-10-09- 2001-10-12 2001-10-24	Interviews with personnel manager, The Norsk Hydro Research Center, Porsgrunn (Porsgrunn) Interviews with participants in the Omacor™ project (Porsgrunn) Interviews with three researchers nominated for the Birkeland Award 2000 (Porsgrunn) Guided tour The Norsk Hydro Industrial Museum (Porsgrunn) Document review ------------------ Interviews with participants in the Omacor™ project, (Oslo) Document review (The Norsk Hydro Corporate Center, Oslo)	8	8	4	84	Field notes Tapes Tran-scripts
November 2001 2000-11-26	Interview with participant in the Omacor™ project (Trondheim)	1	1	1	28	Field notes Tape Tran-script

Time period	**Description activity**	**# of interviews /conver-sations**	**# taped**	**# transcribed**	**# of tran-scribed A4 pages**	**Type of data**
December 2001 2001-12-04-2001-12-07 2001-12-10-2001-12-14	Interviews with participants in the Omacor™ project (Oslo, Skien) Interviews with participants in the Omacor project™ (Porsgrunn) Document review	7	7	7	137	Field notes Tapes Tran-scripts
January 2002 2002-01-07-2002-01-12	Interview with a member of the Omacor™ project (Oslo) Interview with participant in the Omacor™ project (Porsgrunn) Interview with researcher at The Norsk Hydro Research Center, Porsgrunn	3	1	1	24	Field notes Tape Tran-script
Total Omacor™ project		32	19	15	322	
August 2002 2002-08-29-2002-08-29	Participation at the meeting “Industry, Academia and Research. Friction, Plasticity and Fracture: Engineering problems that pose fundamental basic research questions” (Oslo)					Field notes
September 2002	Conversation/ ”Crash course” in aluminum extrusion with researcher at SINTEF,Trondheim	6	5	5	83	Field notes Tran-scripts Tapes

Time period	Description activity	# of interviews /conver-sations	# taped	# transcribed	# of tran-scribed A4 pages	Type of data
2002-09-10- 2002-09-13	Interviews with participants in PROSMAT Extrusion projects Guided tour at the press plant Document review					
November 2002 2002-11-05- 2002-11-08 2002-11-28	Interviews with participants in PROSMAT Extrusion projects (Karmøy) Interview with Research Director, The HA R&D Center, Karmøy, (Karmøy) Interview with foreman at the die workshop at the extrusion plant, (Karmøy) Interview with head of Technical Service, The HA R&D Center, Karmøy (Karmøy) Document review (Karmøy) Interview with NTNU professor (“professor X”) in the PROSMAT Extrusion Steering Committee (Trondheim)	6	6	6	112	Field notes Docu-ment review notes Tran-scripts Tapes

Time period	Description activity	# of interviews /conver-sations	# taped	# transcribed	# of tran-scribed A4 pages	Type of data
December 2002 2002-12-06 2002-12-10	Interview with project manager for Hydro project linked to PROSMAT Extrusion Subproject 2 (Raufoss) Interview with NTNU professor (“professor X”) in the PROSMAT Extrusion Steering Committee (Trondheim)	2	2	2	51	Field notes Tran-script Tape
March 2003 2003-03-10 2003-03-13-2003-03-14	Interview with NTNU professor (“professor Y”) in the PROSMAT Extrusion Steering Committee (Trondheim) ------------------ Interviews with participants in PROSMAT Extrusion projects (Oslo) Interview with researcher at SINTEF Materials Technology, Oslo (Oslo) Interview with representative of the The Research Council of Norway (Oslo)	8	8	8	195	Field notes Tran-scripts Tapes

Time period	Description activity	# of interviews /conver-sations	# taped	# transcribed	# of tran-scribed A4 pages	Type of data
2000-03-20 2000-03-25	Interview with NTNU professor (“professor X”) in the PROSMAT Extrusion Steering Committee (Trondheim) ------------------ Interview with participant in PROSMAT Extrusion (Oslo) Interview with professor in the PROSMAT Extrusion steering committee (Oslo)					
April 2003 2003-04-02 2003-04-03-2003-04-04	Interview with participant in PROSMAT Extrusion (Trondheim) Interviews with participants in PROSMAT Extrusion (Raufoss)	5	5	5	122	Field notes Tran-script Tapes
June 2003 2003-06-11-2003-06-13	Interviews with participants in PROSMAT Extrusion (Karmøy) Document review	2	2	2	34	Field notes Tran-script Tapes
Total PROSMAT Extrusion		29	28	28	597	
Total		61	47	43	919	