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A Methodology for Production Development

- The Body of Knowledge Approach -

Doctoral thesis
for the degree of doktor ingeniør

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Abstract

The development of production line and facilities is without doubt a crucial task for the discrete goods producing industry in order to gain the competitive edge and the attention of the customer. This trend started already in 1969 when Skinner emphasised the strategic importance of manufacturing and that neglecting it could result in production which is time consuming and expensive. As well as this, the evolution in the manufacturing environment over recent years has resulted in the need to consider the whole product life cycle and hence the continuously shortening of the "Time to Market" period for new production facilities with ever higher quality requirements at lower costs. [Womack 1990, Pawar 1994, Case 1998, Wu 2000, Maffin 2001, Reid, 2002, Vonderembse 2003, Swift 2003]

The objective of this paper is to determine a Body of Knowledge for production development to enable small and medium sized enterprises (SME) to shorten their "Time to market" and thereby increase their profit margin. In this thesis it will be investigated how in particular each category of this Body of Knowledge will contribute to production development and how they can be merged into a generic methodology for production development.

Literature revealed that there exist three different perspectives to production development which developed historically, namely the traditional and the down and upstream perspective. It could be concluded that the Body of Knowledge for the sequential traditional approaches was formed out of three categories, Production Development Process, Tools and Technology. The upstream and downstream perspectives are concurrent approaches and to date the Body of Knowledge has evolved over the years into five categories: Integrated Product Development, Multidisciplinary Teams, Project Management, Tools and Technology.

Since these categories cover more than just production development it was necessary to screen these adjoining fields for the particular contribution to production development. Finally, all the contribution could be merged into one overall production development methodology. This methodology describes the process for a systematic approach to production development which is based on the fact that it includes the complete Body of Knowledge. To adjust this methodology for the different production development projects in industry, a production development process template was integrated which enables small and medium enterprises to adapt the development process to their individual needs. The determination of such a generic methodology for production development based on its Body of Knowledge now enables now small and medium sized enterprises to approach production development generically and by that handle the development of production facilities more effective with regards to time and quality for ever more complex products.

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Eltarvåg, May 2005

Christof Schätz

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Terminology

Throughout this research work, I found manufacturing terminology is often confused and it is necessary to clearly define the main terms to create a common understanding on the terminology used.

The main distinction required is that between “manufacturing” and “production”. Kalpakjian [2001] states that the term “manufacturing engineering” is used in the United States and is equal to the term “production engineering” used elsewhere. However, in this thesis I will use a more refined definition that can be found in CIRP [1990], which is supported by Hitomi [1994].

The CIRP [1990] defines “manufacturing” as:

> *Manufacturing is a series of interrelated activities and operations involving the design, material selection, planning, production, quality assurance, management and marketing of the products of the manufacturing industries*

and “production” as:

> *Production is the result or output of industrial work in different fields of activities, e.g. oil production, energy production, manufacturing production. (This is an output)*

Based on CIRP [1990] it can be argued that “production” is a part of “manufacturing”.

1 Introduction

1.1 The Manufacturing Environment Today

The leading question, which triggered this thesis, was the quest to understand what is needed to successfully plan and implement a production facility. This question arose from my participation in production development projects, where this question remained unanswered in its totality. I often experienced answers such as "this is too complex to describe" or "this depends on the situation", but even experienced engineers did not have a satisfying concept for a generic approach to develop production facilities.

The development of production line and facilities is without doubt a crucial task for the discrete goods producing industry in order in order to gain the competitive edge and the attention of the customer. This trend started already in 1969 when Skinner emphasised the strategic importance of manufacturing and that neglecting it could result in production which is time consuming and expensive. Consequently, Skinner unintentionally moved the development process of such production systems into the spotlight as well.

Since 1969 a lot has changed in manufacturing and with that the primary scope of its development. While in the 1960's pure mass production was prevailing to increase the output, industry strove for quality with uniformity and zero-defect production in the 1970's. The 1980's were dominated by more variety and flexibility while still maintaining a high productivity and quality. Finally in the 1990's the customer's demand changed toward novelty and new products every year [Thurner, 1999]. This evolution led to the dramatic decrease of the development lead-time with much smaller market windows. These market and technology trends are expected to continue in the future placing even greater demand on the manufacturing environment [Swink, 1996]. Thus, today's uncertain and dynamic environment presents a fundamental challenge to the new product development process of the future [MacCormack, 2001].

This evolution in the manufacturing environment resulted in the need to consider the whole product life cycle and hence continuously shortening the "Time to Market" period for new production facilities with ever higher quality requirements at lower costs. [Womack 1990, Pawar 1994, Case 1998, Wu 2000, Maffin 2001, Reid, 2002, Vonderembse 2003, Swift 2003]

This thesis focuses on the Norwegian good producing industry and it is important to realize that this industry is mainly formed of small and medium sized enterprises (SME). According to the Norwegian Statistical Office about 97% of the goods producing industry are small and medium sized enterprises with less than 200 employees [SNB, 1999]. Like the business environment worldwide, the Norwegian

SMEs are also confronted with the evolution of the manufacturing environment and in addition to this have to tackle outsourcing and lower investments levels [DN, 2003, 2004], [SNB, 1999], [TU, 2003, 2004]. Therefore, the fast development of new products, and with that their production facilities, is very important to sustain the market and the Norwegian small and medium sized enterprises have to manage the transit in the new manufacturing environment. With the increasingly competitive environment, companies have to develop strategies that incorporate the new uncertain nature of today's manufacturing environment as an opportunity rather than a problem [Yang, 2004].

1.2 Small and Medium Sized Companies (SME) in Development Networks

Today, the picture of a stand-alone company linked to its customer and suppliers only by delivery and procurement of products is not longer valid [Wiendahl, 2002]. Supplier involvement in product development is generally regarded as a strategic benefit to product development time, cost and quality [Lakemond, 1999]. This is a typical description of Norwegian SMEs where products are developed and produced in development networks and where the involvement of the supplier or toolmaker can range from an independent realization of a set of specifications to the direct integration into the product development team. There is a tendency where some companies would prefer to collaborate with other companies rather than invest into a resource that might be scarcely used when the development activities end [Huang, 2003].

There are several motives for building development networks. The market is getting more competitive and because of that products are becoming too complex to be handled by a single organization. In addition it is widely accepted that product development needs a concurrent approach with multi-disciplinary activities and the newest available technology, such as a digital factory. But since an increased number of developed technologies are available companies are often not able to purchase technology and to development the needed experts in-house. Outsourcing philosophies have forced the companies since the 90's to concentrate on their core competences [Chase, 1998]. As a consequence suppliers gained more and more responsibility in their customer's product technology and especially in product development [Maffin, 2001]. Such suppliers no longer compete for orders based on cheap labour, but with advanced engineering skills, equipment and short lead times to the customer [Chan, 2002]. Therefore, suppliers have a strong impact on product as well as production development times and efficiency. All in all supplier and customer seek a stable and "win-win" relationship, which often results in long-term and hierarchic relationships with the supplier.

This thesis focuses on SMEs in Norway which in general do not develop complex products themselves but rather rely on networks for product development. These SMEs are considered as suppliers or product owners with the task of developing production lines, cells or tools. To consider such a type of industry one has to realize that there are different corporate characteristics compared to a larger company.

The major characteristics are listed below:

- SMEs are strongly owner-manager driven. Much of the time of the decision maker is spent on doing routine tasks. In many cases, they are family run.
- SMEs are driven by the demand for improving productivity, cutting costs and ever decreasing life-cycle phases.
- SMEs do not have extensive processes or structures. They are run by one individual or a small team, who take decisions on a short time horizon.
- SMEs are generally more flexible, and can quickly adapt the way they do their work around a better solution.
- SME’s entrepreneurs are generally "all-rounders" with basic knowledge in many areas. They are good at multi-tasking.
- SMEs are more people than process-dependent. There are specific individuals who do certain tasks, with experience and knowledge enable them to do so.
- SMEs are often less sophisticated, since it is much harder for them to recruit and retain technology professionals.
- SMEs focus more on medium-term survival than long-term profits.
- SMEs do not focus on efficiencies. They end up wasting a lot of time and hence money on general and administrative expenses.
- SMEs are time-pressured and therefore they want a solid relationship they can count on for top-quality service. They reward that with loyalty and repeat business.
- SMEs want a solution, not a particular machine or service.
- SMEs focus on gaining instant gratification with technology solutions. They must be simple to use, easy to deploy, and provide clear tangible benefits.
- SMEs do not necessarily need to have the “latest and greatest” technology. The solution can use "lag technology", for example one generation old, so it becomes cheaper to obtain and to use.

1.3 Dilemma of Production Development in SMEs

The dilemma for Norwegian SMEs in development networks is manifold. The evolution of the manufacturing environment has had a lasting effect on the development of production facilities. Repeatedly companies fail to get products on the market in accordance with their own schedule and the failure can have a long term financial repercussions. For example in the electronic industry a six month delay means a 33% loss in the life cycle profit [Toth, 2000]. This effect is illustrated in figure 1.3-1.

SMEs in particular face a similar situation in meeting the market’s requirements. At the beginning of a new development project the product owner either negotiates a fixed price and a delivery time for the supplied parts or the SME has to meet the markets target price. This differs from former times when the selling price was floating until the end of the development project. The supplier’s profit is thereby determined by the difference of the production development costs and selling price of the total volume. A delay in “Time to Market” is in this case delaying the Break Even Point and decreases as a consequence the planned profit. In extreme cases the profit can completely vanish or the project can never reach the Break Even Point and therefore have a life time deficit.

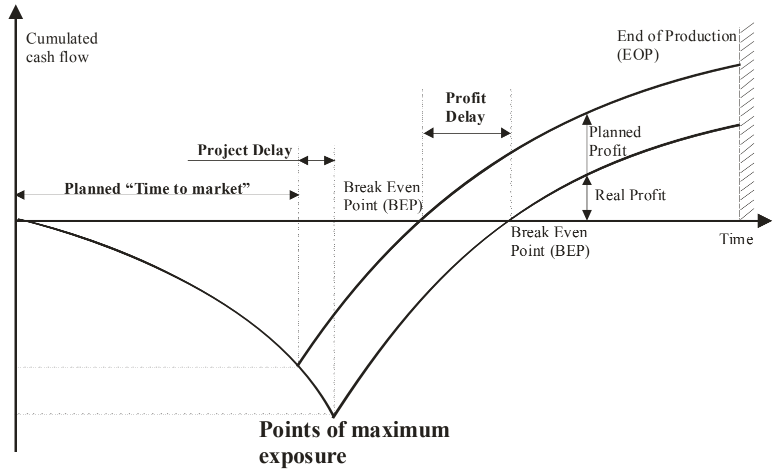


Figure 1.3-1: Project life cycle costing

To prevent this effect, a paradigm shift took place during the 1980s and 1990s with the advent of the philosophy of concurrent engineering. This was driven by the desire to shorten product and production development time [Winner, 1988] and thus raise the planned profit or decrease product costs. Before, traditional "over the wall" approaches were used, which are sequential by nature as illustrated in Figure 1.3-2 below. The consequence of the sequential approach is that products are designed with a limited exchange of information and ideas, and people late in the sequence do not have any input to earlier decision stages. As a result, poor decisions are made [Vonderembse, 1966], which result in longer development times and costs.

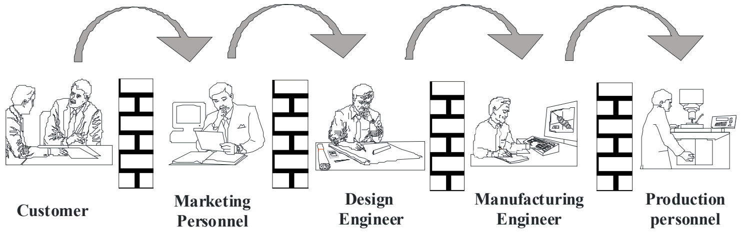


Figure 1.3-2: "Over the wall" engineering

Today, parallel approaches are employed, which are referred to as concurrent engineering, see figure 1.3-3. Concurrent engineering is characterized by the early involvement of the different functional disciplines and parallelism of sequential activities [Haque, 2000]. They facilitate early involvement of all "downstream" links in the decision chain. While "upstream" work processes have to invest more time into planning, "downstream" work processes save time and costs. Several studies have demonstrated that this approach can result in a shorter "Time to Market" [Prasad, 1996].

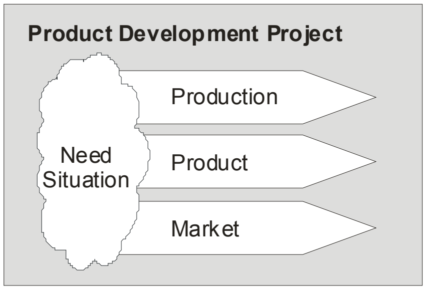


Figure 1.3-3: Product Development Project [Andreasen, 1986]

Further, it can be seen from figure 1.3-3, that the development of production lines has become a stand-alone core discipline, which is part of the product development process right from the beginning. This new discipline has not only to handle the new more dynamic and uncertain manufacturing environment but also more complex products. Consequently, SMEs have to accept the new role and become accustomed to early involvement. This requires new development and communication tools for SMEs.

For an SME a new production is often developed in a network, where the product development lead time depends not only on their own enterprise but to a large extent on the cooperation partners. A typical example is shown in figure 1.3-4.

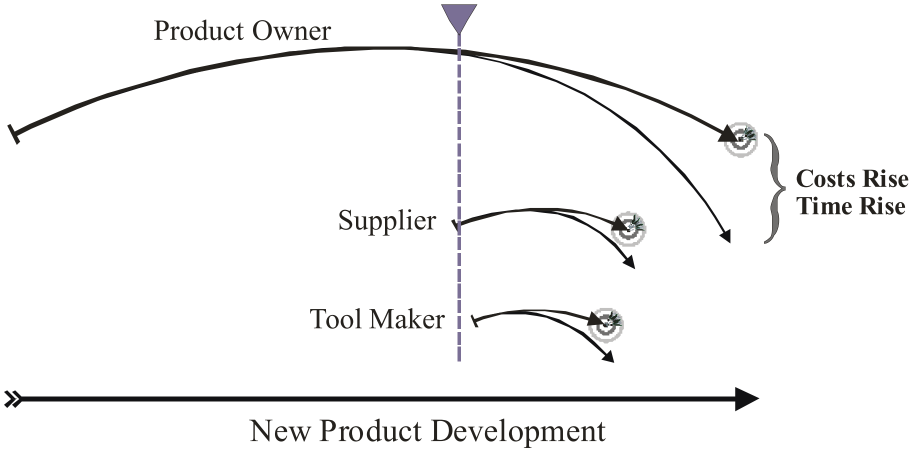


Figure 1.3-4: Supplier in a network

Therefore, SMEs need to have a structured process of production development, which reconciles the development process with the development network, in order to easily discover potential or actual delays and implement corrective actions.

The competing production development scopes of the different development partners in combination with complex products require more complex development tools, such as a digital factory. This means large investments, which is a basic problem for SMEs, but could be shared in a development network.

All in all the new discipline of production development has to be integrated into the corporate structure of SMEs. The main problem is that this discipline is hardly described as part of the core development team's responsibility. Therefore, a better and clearer understanding of the production development process in a development network is necessary. This will result in a shorter "Time to Market" and raise the competitive edge of any SME.

1.4 Research Objective and Research Questions

It has been shown, that all SME are presently confronted with the participation in new product development already from the early design stages, and that the sequential way of product and production development has been phased out to be replaced by concurrent approaches. These concurrent approaches are carried out in networks, where SMEs as suppliers are often responsible to the product owner for substantial contribution to the future product. The involvement at the conceptual design stage of the product owner is widely accepted and used, but the readiness for such an involvement is often in an infant state at SMEs.

This thesis focuses on production development within a concurrent development approach. In this thesis, production development is defined as the interface between product design and regular production and as an interface deals with the planning and industrialization of new discrete products in new production cells or lines, as shown in figure 1.4-1. Production development itself is part of the product realisation process and has consequently a direct influence on the product development lead time.

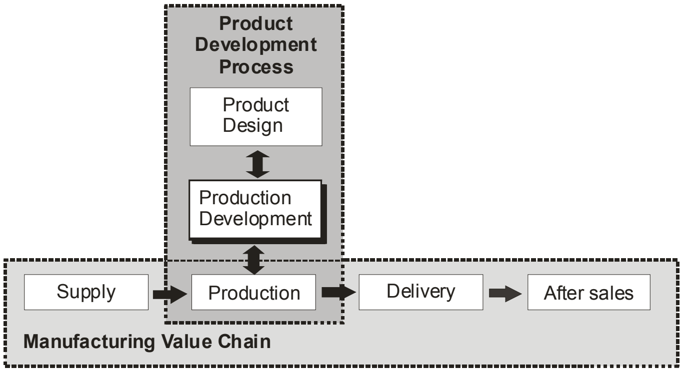


Figure 1.4-1: Production Development

As discussed earlier, production development is considered as a distinct core development discipline in concurrent engineering and it needs to be described properly. However, so far this discipline has just been described in parts from different perspective in a very general manner; see for example Andreasen [1986], Garside [1999] or Ulrich [1995]. In this thesis the approach is to describe the profession and discipline of production development by determining the Body of Knowledge used. The Body of Knowledge is an inclusive term that describes the sum of knowledge within a profession or management practice [Armstrong, 2001]. With the growing complexity and uncertainty of the new manufacturing environment the Body of Knowledge might grow as well and it needs to be applicable for any SME in a development network. Therefore the Body of Knowledge of production development needs to be determined generally. The SMEs can use this Body of Knowledge by adapting the different knowledge categories individually to their business environment. Further, the results of this thesis will provide the production development team with the necessary knowledge for a successful production development process.

The objective of this thesis is to investigate how the generic Body of Knowledge for production development has been evolved from traditional approaches towards more modern concurrent engineering approaches. Further to this, I will assess the consequences this evolvement has for SMEs as suppliers in a development network.

Based on this research objective the hypothesis and research questions for this research work are as follows:

Research Hypothesis:

The creation of a generic Body of Knowledge for Production Development in a Concurrent Development Process enables small and medium sized enterprises (SME) to shorten their "Time to Market" and thereby increase their planned profit margin.

Research Questions:

- *Which Body of Knowledge describes generically the production development process?*
- *How in particular can each category of the Body of Knowledge contribute to the production development process?*
- *How can these contributions be merged into a generic methodology for production development and adapted to the new manufacturing situation of SMEs in a development network?*

1.5 Disposition of this Thesis

The disposition of this thesis comprises four main sections. In chapter 2 the research methodology used in this thesis is presented. Chapter 3 summarises the findings of a literature research on production development and the adjoining fields of project management, tools and technologies in product development and multidisciplinary teams. In chapter 4 the theoretical foundation to production development is discussed and the contribution to production development of the adjoining fields is deduced. Finally in chapter 5, production development and its presented adjoining fields are merged into a Body of Knowledge for production development and further developed into a generic approach to production development

2 Research Methodology

This chapter describes the scientific approach used in this thesis. First will be described the different types of reasoning in research and a general approach to information sought. Second, will be described the scientific approach used in this thesis to achieve the desired results.

2.1 Research Science

There is no generally accepted definition of science, but the basic idea behind science is to acquire systematically general knowledge not known before [Roozenburg, 1995]. Fjeldaas [unknown] view of science is that, among other qualities, it should have some power either to explain the past or to predict the future. In any case in order to acquire new knowledge research demands a methodological approach.

One possibility is to classify research methodology according to their pattern of reasoning. Two different approaches are commonly known, namely deductive and inductive research. Deductive reasoning implies a given material implication and given antecedent, so that the researcher can conclude unerringly the consequence; the reasoning is watertight [Roozenburg, 1995]. In such a research work a hypothesis is established as a start and verified or rejected. The achieved one solution is then valid for all given examples. If the achieved solution fails once the hypothesis fails. Typical areas to find such research work are in natural science and to a certain extent technology. However, there can also be several solutions to the problem. In inductive reasoning the scientist seeks for a general statement about the world in terms of law and theories [Roozenburg, 1995]. During inductive research the conclusion is validated by adding more and more premises. Induction starts from a particular observation and ends with a general statement. This type of research is important in empirical and human science. The starting point is usually a problem statement. Such research implies a great amount of creativity and is considered more challenging than deductive research [Fjeldaas, unknown].

Within these types of research, the type of information search can be classified as qualitative or quantitative. The purpose of qualitative research is primarily to describe a situation, phenomenon, problem or event; the information gathered through use of variables measured on nominal or ordinal scales, and if done to establish a variation without quantifying it [Kumar, 1999]. Applications can typically be found in social science, in the form of case studies or action research. Methods used include observation, questionnaires, documents and the researcher's experience. On the other hand, quantitative research aims to qualify the variation in the phenomenon, situation or problem. If information is gathered using predominantly quantitative variables and if the analysis is geared to ascertain magnitude of the variation the study is classified as quantitative [Kumar, 1999]. This information seeking is especially applicable in natural science and includes survey methods like laboratory experiment or mathematical methods. Isaksson [2001] summarizes, that quantitative research is characterized by looking at the problem from the outside and measuring the assumed objective's reality, while qualitative research works with the interpretation and allows the researcher to have an inside view. It should be noted, that a research does not need to opt for one approach exclusively. Both approaches can appear in the same research work, and for some studies it will be necessary to combine both.

2.2 Methodological Approach Applied in this Research

This research work was conducted in the period from 2001 until 2005. The problem statement in the thesis is based on the author's experience and observation in industry of the development of the production line and facilities. To strengthen the observation of a missing general approach to production development a first literature review was conducted. The reason behind this initial literature research was on the one hand to find "first source", well accepted and guiding literature and on the other hand to find recent literature and new articles that show the tendency towards the need of such a methodology. Together all this information lead to the hypothesis and research questions. The approach used is inductive with qualitative data.

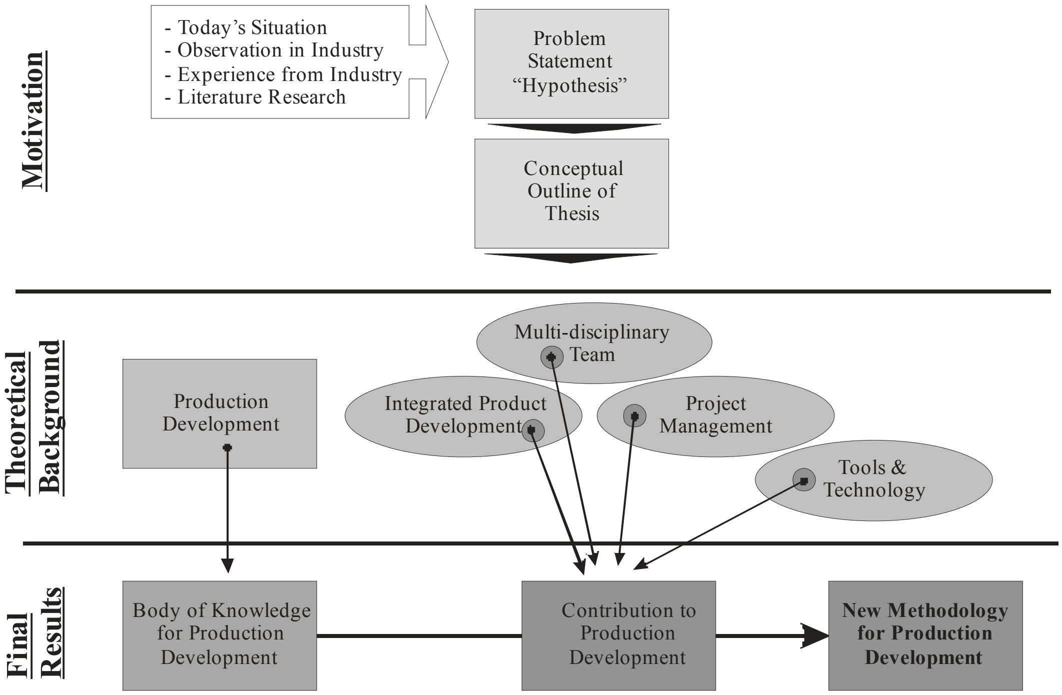


Figure 2.2-1: Thesis approach

Based on the hypothesis and the research question the outline of the thesis was established as illustrated in figure 2.2-1. Seeing this figure, the working procedure in this thesis was from the “left to the right”. The methodology used to identify the theoretical background was a second more detailed literature research. The primary field was production development. Since the literature contributes to production development is widely spread it was necessary to screen various scientific fields and extract the relevant information. The information was then analyzed and discussed. To ensure a comprehensive overview, this literature review and its analysis was conducted in an iterative process as long as no new important information could be found. To achieve the categories of the Body of Knowledge for production development an accepted analogy of product development was used as a basis and adapted for production development. The categories for production development were then achieved both with inductive and deductive reasoning.

Having determined the categories, it was then necessary to search them in detail for their particular contribution to production development. The basic assumption was that the aggregation of these single contributions could be summarized into the Body of Knowledge for production development. A third literature research was chosen in each of theses four categories. Thereby, literature from well known authors and relevant article in scientific journals were analyzed. By comparison of the literature with the characteristics of production development found in the second literature review, the relevant information could be extracted.

At this stage of the thesis the different categories of the Body of Knowledge for production development were determined in detail. The aim of this thesis is to achieve a new methodology for production development based on this Body of Knowledge. The information and results found so far were isolated without showing the interrelation to each other. Deducing the interrelations of the different categories lead to the Body of Knowledge for production development and, with induction, a new methodology of production development was established

3 Theoretical Foundation

This chapter describes the results of a literature search for sources describing production development or one of its various aspects. For that literature was first screened which mentioned production development directly. In a second step the integrated product development process was investigated where production development was an embedded function. To complete the various aspects adjoining fields of project management, multidisciplinary teams and tools & technologies are described which have a connection to production development.

3.1 Production Development

As mentioned in Chapter 1.4, the development of production lines and cells for discrete products is part of the overall product development process, see figure 3.1-1. Production development is a process which describes the function of management, which plans, direct and controls the physical means used to manufacture the products [Koshal, 1993]. Spur [1994] gives a more detailed definition for the production development process as part of the overall company business strategy with the objective being to translate the planned investment into a real production plant within defined economic parameters as well as planned output. Therefore, the production development process is the foundation for a competitive and profitable manufacturing business [Garside, 1999].

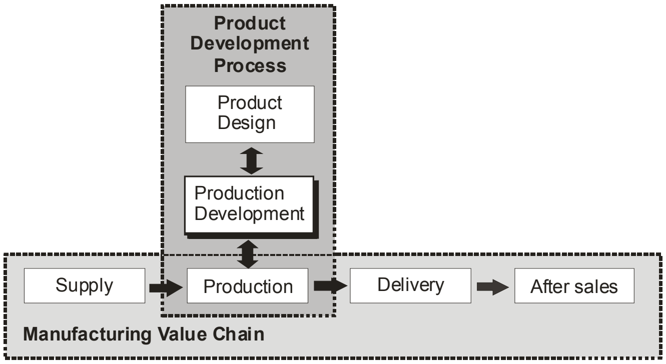


Figure 3.1-1: Production Development in an industrial setting

In principle, changes of production lines and cells can be split into two categories: technology development and production development, see figure 3.1-2. In contrast to technology development during production development a new product is designed at the same time as the production is developed. This paper deals with production development which is defined as the interface between product design and regular production and deals with the planning and industrialization of new discrete products in new production cells or lines.

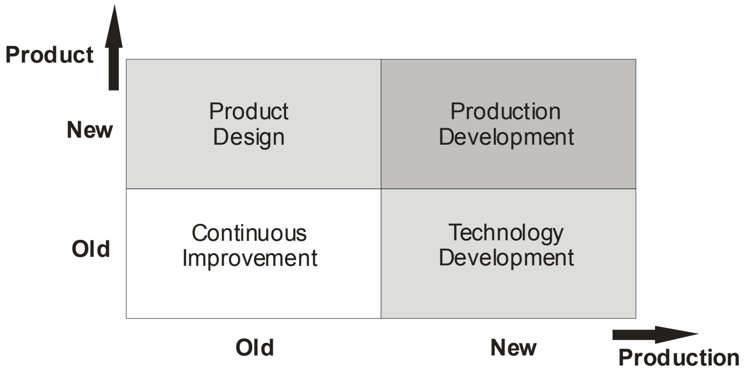


Figure 3.1-2: Product-Production matrix

Note that the production development process itself is part of the overall manufacturing system design process. Thus not only relevant production technology has to be considered, but also all linked fields such as human resource, logistics and economics in order to develop an effective and efficient facility.

The scope of production development is to integrate process and manufacturing issues from the conception, planning, and implementation of economically justifiable production processes designed to produce a variety of goods in a definable period of time [Curtis, 1988]. Realizing a production facility from its first plans into a live plant follows a systematic and goal driven approach.

Several different approaches can be found in literature, see for example Eversheim [1997], Spur [1994], Andreasen [1986], Clark [1993], Ulrich [2000], Vonderembse [1996]. A basic distinction of these development cycles is the differentiation between sequential and parallel approaches. Historically, the sequential approach emerged prior to the parallel processes.

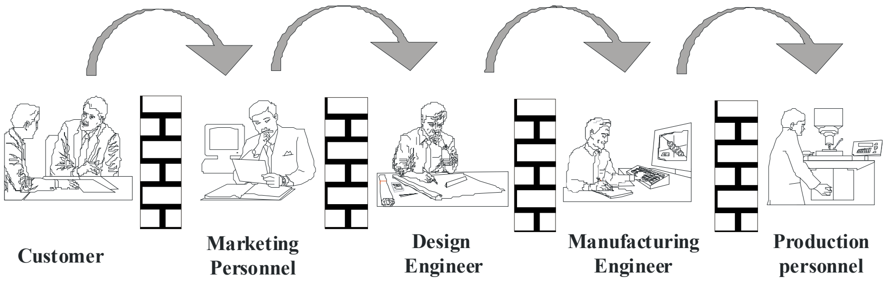


Figure 3.1-3: “Over the wall” engineering

As mentioned before this transition took place during the 1980s and 1990s with the upcoming concurrent engineering philosophy. The reason was the desire to shorten product development time [Winner, 1988]. Traditional, “over the wall” approaches are sequential by nature as illustrated in figure 3.1-3. The major disadvantage of this approach is that products are developed with a limited exchange of information and ideas, and people late in the sequence do not have any input to earlier decision stages. As a result, poor decisions are made [Vonderembse, 1966], which resulted in longer "Time to Market" and higher development costs.

Modern parallel approaches are referred to as concurrent engineering, see figure 3.1-4. They emphasise earliest involvement of all "downstream" departments into the design decision. Now, while "upstream" work processes have to invest more time into planning, "downstream" work processes save time and costs. Several studies have demonstrated that this approach can result in a shorter "Time to Market" [Prasad, 1996].

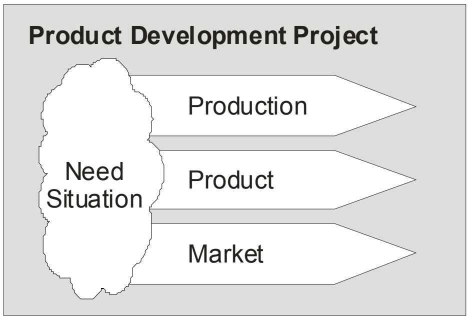


Figure 3.1-4: The parallel development process [Andreasen, 1986]

Nevertheless, the traditional approach of sequential work processes is still the basis for planning and implementation of new production facilities. One of the highest "walls" in the sequence has traditionally been – and still is – between the product design and the production department. The "wall" can be characterized as the handover of the final product specification from the design department to the production department. As a consequence, two potentially different points of view to production development emerge on the two sides of the "wall": that of the upstream department before the final product specification is made and that of the downstream department after the final product specification is made.

Finally, three different views to production development can be summarized as:

- The traditional sequential approach
- The concurrent approach from the perspective of the downstream departments
- The concurrent approach from the perspective of the upstream departments

In the following, these three different views will be described in greater detail, as mentioned in the literature.

3.1.1 Traditional Production Development Process

The traditional process of developing production facilities, which has its origin in the 1950s, is described by the German researchers Spur [1994] and Eversheim [1997]. Both authors relate to the REFA association documents and outline an activity-based approach see figure 3.1.1-1. The terminology Eversheim [1997] uses in his approach differs much from other authors. He uses the expression "work preparation", which he divides into “work planning” and “work controlling”. According to CIRP [1990] these terms equal production planning and production control.

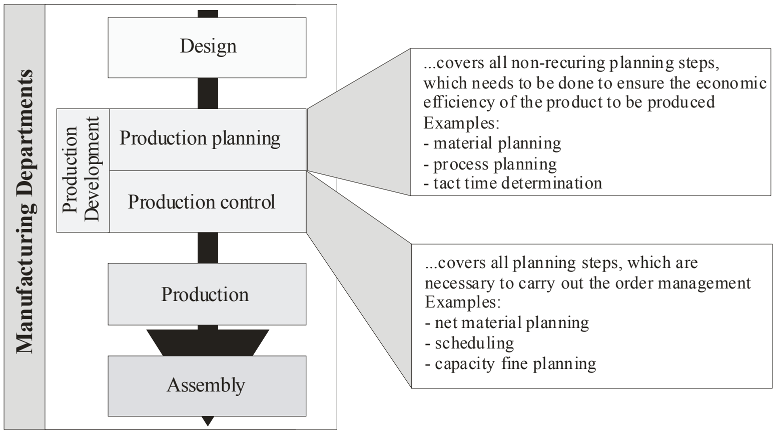
Eversheim [1997] describes in figure 3.1.1-1 the relevant development activities and thereby presents his view of a production development process. He cites thereby the dissertation from Minolla [1975], who in turn divides the development of production facilities into two distinct phases:

- the production planning phase and
- the production control phase.

According to Eversheim [1997] production development is the medium and long term perspective of the production planning phase. The length of this planning depends on the number of necessary work steps and their level of detail.

So, production development in a traditional perspective comprises of the sequence of the following tasks:

- Machine and tool planning
- Storage and transport planning
- Human resource planning
- Layout and facility planning
- Investment planning



...covers all non-recuring planning steps, which needs to be done to ensure the economic efficiency of the product to be produced
Examples:
- material planning
- process planning
- tact time determination

...covers all planning steps, which are necessary to carry out the order management
Examples:
- net material planning
- scheduling
- capacity fine planning

Figure 3.1.1-1: The production development process [Eversheim, 1997]

The characteristic of this in comparison to the short term planning is the much higher degree of freedom of development. Spur [1994] and Eversheim [1997] agree that the base for the traditional production development process itself is the business strategy and the activities are performed in a sequence of iterative steps. Eversheim [1997] emphasizes the strategic importance of production development as the interface between product design and operations. Spur [1994] cities the approach from Kettner [1984] as a comprehensive procedure to plan a new production facility. Their focus is mainly on the activities required to construct the production facility and its layout and on cost planning. Other design activities are assigned to other planning and development disciplines, which have to contribute to the overall product realization process.

Further Eversheim [1997] suggests that the production development process is performed by a distinct department, called “production development department”. This department should build the bridge between the designer and the operator.

It can be seen that the activities of the production development department are described as sequential and that the downstream and upstream departments are not included in these activities. In case of changes - such as product changes or changes in customer requirements, - this approach leads to cost- and time-intensive iterations. Based on this realization Eversheim [1995a, 1995b] recommends somewhat parallel activities similar to the concurrent engineering approach and suggests two more adequate approaches:

- The early involvement of the production developer in the product design and development process and the involvement of the production staff in the detailed planning of the production facility.
- The department of production development is still the link between the product design and the downstream production. But note that an involvement of the production staff directly in the product design process is not mentioned.

3.1.2 Concurrent Approach from the Perspective of the Downstream Departments

In literature, approaches to production development from downstream functions can be found in several engineering disciplines, such as operations management [Clark, 1993], [Chase, 1998], [Reid, 2002], [Vonderembse, 1996], [Markland, 1995], industrial management [Garside, 1999] and manufacturing system design [Wu, 1994]. Other approaches mentioned in literature cover special phases in the production development process such as process planning Swift [2003], Scallan [2003] or the design and development of special tools such as injection moulds see Altan [1993, 2001], Rosato [2000] and Britton [2001].

A generic development approach is provided by Wu [1994]. It is based on a generic system approach to problem solving and focuses on the design of a series of value-adding manufacturing processes to convert the raw material into more distinct forms and eventually into finished products [Wu, 1994]. He describes the various aspects and processes of advanced manufacturing technologies in the system context. He does not discuss the detailed activities or decisions during the design of a manufacturing system, but he emphasizes the necessity to create an overall framework for manufacturing system design including production development. To realize this, Wu [1994] creates a system life cycle and considers the manufacturing system design as a problem and recommends decomposing the problem into sub-problems. Solving the sub-problem in a system view solves the overall problem. The purpose of such an approach is not a collection of separate departments, but a system, in which the effective interaction of flow of information, materials, personnel, equipment and money guarantees a smoother and more effective overall operation. This in turn supports the relevant business goals [Wu, 1994].

More detailed approaches are illustrated by operation management which includes the complete supply chain. Operation management is the business function, which plans, coordinates, and controls the resources needed to produce the company’s product and services. Its role is to transform a company’s input into the finished product or service

[Reid, 2002]. The production development process is part of this overall transformation process.

Most of the operation management approaches to production development are very similar. Chase [1998] and Clark [1993] give a good description of the operation management view to production development. Compared to the traditional approach, the important improvement in the approach from Chase [1998] is the use of key decisions and key milestones. Key decisions and key milestones define the main difference between the activity based approach and the decision based approach. Furthermore, a concurrent engineering approach is outlined, where cross-functional integration and parallel activities are emphasized.

Chase [1998] points out, that organizing complete projects according to the concurrent engineering philosophy will speed up the product development process. This type of organization differs from the hierarchic organization, which Spur [1994] and Eversheim [1997] use in their approach. The integration and execution of the tasks are performed by multi-disciplinary teams, which is another difference to the traditional approaches. As a consequence Chase [1998] does not suggest any distinct department for production development as in the traditional approach. All activities are project based and need project management activities as support functions. However, assignments of engineering tasks to the different departments or more detailed information about each of the activities are not described. Chase [1998] focuses on the phases of new product development, not the necessary functions and activities. Nevertheless, he emphasizes that production issues are integrated into the product design process right from the start.

Garside [1999] presents an even more detailed step by step procedure and engineering solution to production development based on his own experience as shown in figure 3.1.2-1. Garside (1999) uses the term manufacturing system design instead of production development.

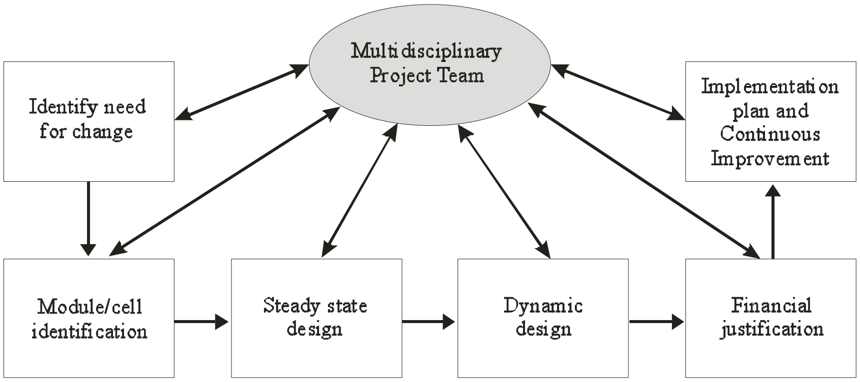


Figure 3.1.2-1: Stage in supply-chain and manufacturing system design [Garside, 1999]

This approach has its roots in the field of industrial engineering and includes tools like procedures, scored checklists and project reviews based on company business strategy. Garside [1999] emphasizes that in order to be indeed a world-class system the manufacturing system must be systematically developed further by applying continuous improvement systems. He addresses his procedures to managers and multi-disciplinary project teams. These teams can change during the development process in order to meet the different requirements, but a full-time core team should be present throughout the entire project. Traditional department structures are no longer necessary, since team members are directly assigned to the project. By this, Garside [1999] takes a concurrent approach to the production development problem for granted.

Garside [1999] defines all tasks and activities of production development as problems, which need optimum solutions. He supports Wu [1994] that solving sub-problems contributes to the solution of the overall problem. Further he introduces a "problem owner", who is responsible for the defined problem. The aim is to create an optimized solution, which is different to the traditional approach of optimizing various subsystems [Garside, 1999] and he centres the attention on the problem solving team to carry out the project. This concept is primarily based on the human being, and not on the management system, as the problem solver. This trend strengthens the flexibility of the project teams as well as the entire factory. It also adds project management as a "new" discipline to the production development process. As a result, the team is faced with a "one-of-a-kind" production, which is planned and controlled using project management theories and techniques [Rolstadås, 2002].

Ermark [1997] remarks, that in spite of the impact of project management on lead-time, quality and costs, project management as part of production development is attracting little attention in the production development process.

Specific application of approaches to production development can be found in literature as well. These approaches are numerous and exist for many different products and processes. An example is the plastic mould design process, see for example [Rosato, 2000] and Altan [1993, 2001]. Other authors like Scallan [2003] and Swift [2000] describe the process design of a specific step of the production development process. However, most of the approaches focusing on the solution of this particular design problem and often neglecting the development environment, which they are contributing to.

3.1.3 Concurrent Approach from the Perspective of the Upstream Departments

The area, in which approaches to production development from the perspective of the upstream departments can be found, is product design. A typical activity based generic design process is given by Ulrich [2000], which also includes production issues. Similar approaches can be found in Roozenburg [1995], Pahl [1995], VDI 2221 [1987], Andreasen [1986], Suh [1990] and in the product design review of Schätz [2000]. None of the latter approaches outlines the necessary manufacturing issues nor do they include detailed activities needed to achieve an effective and efficient production facility during product design.

The structure of the approach from Ulrich [2000] is very similar to Andreasen [1986] and Clark [1993]. They integrate manufacturing into the integrated product development process as a distinct discipline. Ulrich [2000] divides product development into five distinct phases from conceptual design to production ramp-up. The start of the development is the mission statement and the output is the product launch. This cycle represents a parallel design process, which is typical for concurrent engineering design, and needs project management to steer all the parallel processes as well as the multidisciplinary team.

Ulrich [1995], Roozenburg [1995], Andreasen [1986] define three functions central to product development:

- Marketing
- Design
- Manufacturing

These functions are also placed for the core team for production development as defined by Chase [1998] and Clark [1993] from the former chapter.

Ulrich [1995] clearly indicates that activities concerning manufacturing must be already present in the very early design stages. This is neglected by the traditional approach described above. The early involvement of manufacturing is also emphasized by Roozenburg [1995]. He warns against "ready-to-make" products, which proceed directly from product design into production, because this will lead to product failure and longer product development times. Roozenburg [1995] advises an iterative product development process with continuous consultation on production development.

All approaches emphasize the crucial influence of design decisions on the product costs, development time and quality [Pahl, 1995]. This includes the verification of manufacturability in the initial designs. The design architecture is plotted against production requirements to show the possibility of integrating the design into the future production facility. Evaluating the manufacturability of a product also reveals the weaknesses and threats to the design with respect to manufacturing issues. Later in the product design process, manufacturability becomes a criteria in the decision making process to achieve the "best" design. This approach requires a very early involvement of production engineers and therefore demands an improvement in communication among the different departments.

A typical tool to prove manufacturability is the "failure-mode and effect" analysis (FMEA). This method can be applied to the design and to the chosen production processes. Other well known methods are Design for Manufacturing (DFM) and Design for Assembly (DFA). They use checklists and guidelines to improve manufacturability. DFM provides the designer with a set of rules and guidelines to optimize the design regarding manufacturing issues and thereby minimizes manufacturing costs. Consequently, DFM is a method tackling manufacturing issues early without the necessity of integrating production development engineers. Therefore, designers will do well to consult these checklists [Pahl, 1995], Ulrich [1995]. These guidelines and checklists can be on paper or integrated into a CAM system. It is a sort of "best practice" of production engineers for the design of a product and complete reference books for DFM and DFA have been published, such as Bralla [1999] or Boothroyd [1994].

All DFM and DFA methods support the product designer in considering manufacturing issues early in the product design process. Traditionally, the production designer has had very little influence on the products design, so all methods can be applied without the presence of a production development engineer. Yet, it is strongly recommended by most authors to include the manufacturing engineer as experts in the design team and the decision process.

A mathematical approach to DFM is presented by Suh [1990]. The 9th theorem of Suh's axiomatic design states, that the design matrix for a product and the manufacturing process must result in either a diagonal or a triangular matrix for a product to be manufacturable. If not, the product cannot be manufactured. The method is not very well described in literature and the main problem with its application in reality is that it is not always possible to plot the functional domain against the process domain. Vallhagen [1996] concludes that this method is in some aspects still insufficient for designing manufacturing systems.

Furthermore all approaches estimate product costs, which also include also production costs. This requires that a concept of the future production facility exists. However, how the concept of the future production facility is to be obtained is not described.

3.2 Integrated Product Development (IPD)

3.2.1 Background

In the last 25 years concurrent engineering has become the guiding philosophy behind new product development. A successful product has its roots in a well thought out development process. Cooperation between the core disciplines in a multidisciplinary setup during concurrent development is effective in shortening development time and costs. Nevertheless, it is apparent that engineers and managers working in the different core disciplines may have different perceptions and expectations of the concurrent development approach. Moreover, those working in the core disciplines tend to emphasize the importance of their own expertise while viewing all other disciplines as supporting functions, in spite of their equal relevance to the process.

This chapter provides an overview about present integrated product development process models. To do this, literature was surveyed for existing process models or parts of similar development models that had as their focus the development for discrete products.

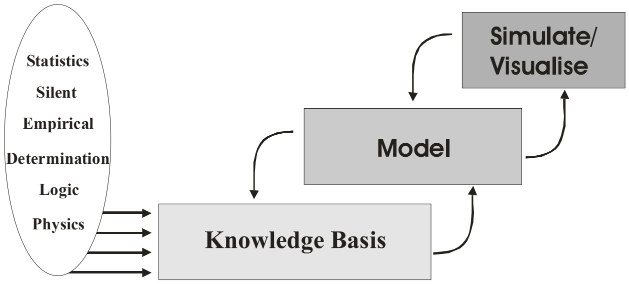


Figure 3.2.1-1: General modelling

In principle, a model for a system is anything to which an experiment can be applied in order to answer questions about the system [Minsky, 1965]. Modelling itself means the process of organising knowledge about a given system [Ziegler, 1984]. Again, a system is a potential source of data [Cellier, 1991]. Figure 3.2.1-1 shows the principle outline of the modelling used in this research work. The depicted system is based on explicit and tacit knowledge.

It can be seen, that modelling is a catalyst to simulate or visualize a given knowledge. Also the source of knowledge can be manifold, such as physical, empirical or statistical sources.

A generic type of model used in this thesis is the SCOR reference model V.5.0 [SCOR, 2003]. Figure 3.2.1-2 is an illustration of the model. The model consists of four different levels. The top level is the process level and describes the scope and the content of the business process. In level two the process is then decomposed into process elements represented by the different development core disciplines. Level three and four lists the tasks and activities of the process elements.

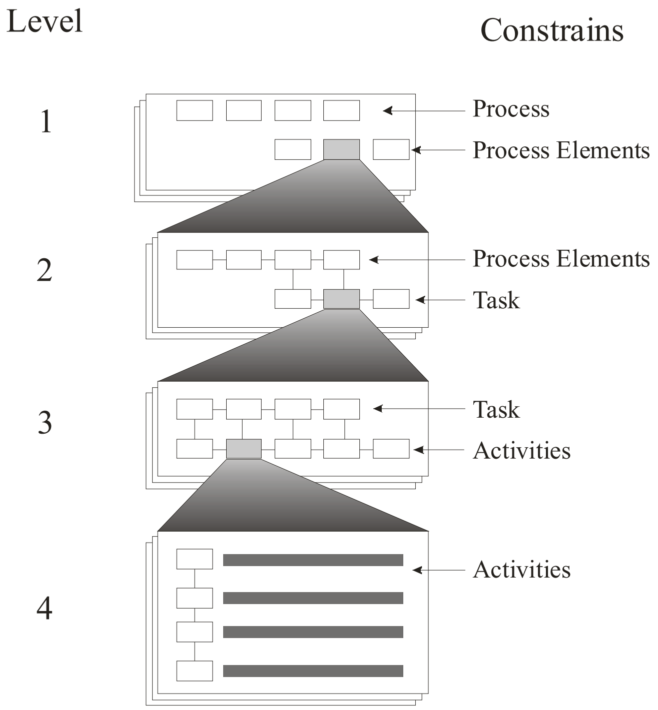


Figure 3.2.1-2: The SCOR reference model V.5.0 [SCOR, 2003]

The level of abstraction is thereby decreasing from level one to level four. Consequently the individual product and production characteristics have more and more influence on the model's lower levels. It can now be seen, that it is unlikely, that a holistic model of concurrent development can be broken down to level three and four. Therefore this research work focuses on the processes and its process elements. The last two levels can be derived then from the individual new product development configuration.

3.2.2 Present Concurrent Development Models

A very common model is originated by Andreasen [1986]. The "Integrated Product Development Model" (IPD), as seen in figure 3.2.2-1, is an idealised model which can be applied on any product development situation. He lists steps that have to happen in a product development process. This model gives the longest path from a recognised need to the product's sale. Not all steps have to be carried out to the same extent. Some steps can be shortened while others are more important, depending on the nature of the product development process. All phases end with a milestone ensuring the quality of the development process. However to achieve this model, it was necessary to base it on the following assumptions:

- The result of product development should be a successful business
- Product development is a creative, multi-disciplinary process
- Product development starts with a need
- Product development is an iterative process……
- …..so we need to map out our course
- Product development consists of market research, development, the establishment of production and sales and ongoing production and sales
- Design activities determine how the phases are divided up
- The regularity of product development determines what happens in the marketing/sales and production phases

All these assumptions where collected in the integrated product development model shown in figure 3.2.2-1.

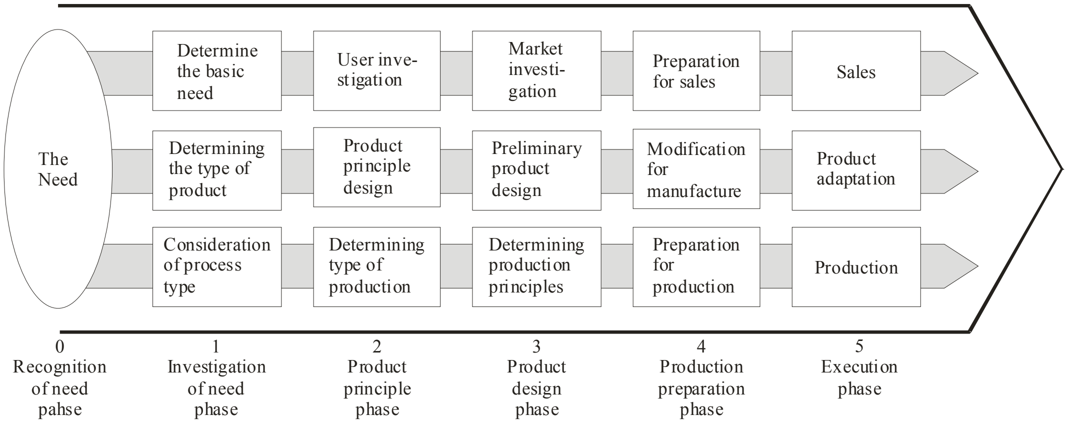


Figure 3.2.2-1: Integrated Product Development Model [Andreasen, 1986]

This model is applicable to a wide array of product development types. In his book Andreasen [1986] mentions the adaptation of the model in pure manufacturing firms, sales agencies, design company, sub-contractors for components or own-assembly and bought-in development design and development. He further mentions that this model can be applied in small or large companies and for production to order and in mass production. Nevertheless, this model is neither a pattern of behaviour and communication nor a project plan.

Ulrich [1995] presents another generic concurrent development process. It is a process of sequential steps or activity which an enterprise undertakes to conceive, design and commercialise a product. Both authors emphasise that many of these steps are intellectual and organisational rather than physical. Further they stress that this development process is applied slightly differently in every company and that even in the same enterprise this process can differ from project to project.

Ulrich [1995] divides the product design cycle into five basic development phases. This cycle describes all development phase as well as parallel ongoing activities and is focused on mechanical engineering. The input is the mission statement and the output is the product launch.

Ulrich [1995] sets this process parallel to the original design cycle and hence integrated manufacture issues early in the design approach. This is a typical concurrent engineering design cycle that needs top management to oversee all the ongoing parallel processes as well as a multidisciplinary team. The process, its task and responsibilities is shown in figure 3.2.2-2.

Concept Development	**System- Level Design**	**Detail Design**	**Testing and Refinement**	**Production on the ramp**
Marketing				
• Define market segments • Identify lead users • Identify competitive products	• Develop plans for product options and extended product families	• Develop marketing plan	• develop promotion and launch materials • Facilities field testing	• Place early production with the key customer
Design				
• Investigate feasibility of product concepts • Develop industrial design concept • Build and testing experimental prototypes	• Generate alternative product architectures • Define major subsystems and interfaces • Refine industrial design	• Define part geometry • Choose materials • Assign tolerances • Complete industrial design control document	• Do reliability testing life testing and performance testing • Obtain regulatory approvals • Implement design changes	• Evaluate early product outputs
Manufacturing				
• Estimate manufacturing costs • Assess production feasibility	• Identify suppliers for key component • Perform make-buy analysis • Define final assembly scheme	• Define piece-part production process • Design tooling • Define quality assurance processes • Begin procurement of long leading tooling	• Facilitate supplier ramp-up • Refine fabrication and assembly processes • Train work force • Refine quality assurance processes	• Begin operation of the entire production system
Other functions				
• Finance: Facilitate economic analysis • Legal: Investigate patent issues	• Finance: Facilitate make-buy analysis • Service: Identify service analysis		• Sales Develop sales plan	

Figure 3.2.2-2: A generic development process [Ulrich, 1995]

Another comprehensive concurrent development approach is presented by Clark [1993], see figure 3.2.2-3. The main purpose of this model is to achieve cross-functional cooperation among the involved disciplines, based on industrial case studies. He achieves a cross-functional integration by describing what the product development core functions do, when they do it and how they get their work done. Like the other two authors, his model is a matrix showing chronologically the different development phases in relation to the functional core disciplines.

	Phases of Development		
Functional Activities	**Concept Development**	**Product Planning**	**Detailed Product and Process Engineering (Phase 1)**
Product Development	Propose new technologies; develop product ideas; build models conduct simulations	Choose components and interact with suppliers; build early system prototypes; define product architecture	Do detailed design of product and interact with process; build full-scale prototypes; conduct prototype testing
Marketing	Provide market based input; propose and investigate product concepts	Define target customer's parameter; develop estimates of sales and margins; conduct early interactions with customer	Conduct customer tests of prototype in prototyping evaluation
Manufacturing	Propose and investigate process concepts	Develop cost estimates; define process architecture; conduct process simulation; validate suppliers	Do detailed design of process; design and develop tooling and equipment ; participate in building full scale prototypes
Key Milestones	• Concept for product and process defines	• Establish product and process architecture • Define program parameters	• Build and test complete prototype • Verify product design
Key decisions	**Concept approval**	**Program approval**	**Detailed design approval**

Continued

	Phases of Development		
Functional Activities	**Detailed Product and Process Engineering (Phase 2)**	**Pilot Production/Ramp Production**	**Market Introduction**
Product Development	Refine details of product design; participating in build second phase prototyping	Evaluate and test pilot units; solve problems	Evaluate field experience with product
Marketing	Conduct second phase customer tests, evaluate prototypes; plan marketing rollout; establish distribution plan	Prepare for market rollout, train sales force and fields service personnel; prepare order entry/process system	Fill distribution channels, sell and promote; interact with key customers
Manufacturing	Test and try out tooling and equipment; build second-phase prototypes; install equipment and bring up new procedures	Built pilot units in commercial process; refine process based on pilot experience; train personnel and verify supply channel	Ramp up plant volume targets; meet target fro quality, yield, and costs
Key Milestones	• Build and test complete 2nd prototype • Verify process tools and design	• Produce pilot units • Operate and test complete commercial system	• Ramp up to volume production • Meet initial commercial objectives
Key decisions	**Joint product and process approval**	**Approval for first commercial sales**	**Full commercial approval**

Figure 3.2.2-3: Integrated Product Development Model [Clark, 1993]

There are some characteristics separating it from the other CDM models. First Clark chooses, similar to Andreasen [1986], milestones and key decision points in the development cycle. Further Clark separates the detailed development phase into two distinct phases. By that he emphasises the importance of verifying the product design and the design of tooling and equipment before the verification of the whole production process. This implies that the production development process is finished after the product design as assumed in the other process models.

Using the SCOR [2003] as a basic model it can be now said that the highest model level represents the concurrent development process. Andreasen [1986], Ulrich [2000] and Clark [1993] now describe the development processes and their process elements as well as the participating disciplines. Additionally Andreasen [1986] and Clark [1993] place gateways between the process elements. Finally four fundamental elements of the concurrent development process can be determined as follows:

- key decisions in integrated product development
- core disciplines in integrated product development
- processes in integrated product development
- process elements of the core disciplines

In the following chapter these four elements will be described in grater detail taking all three mentioned concurrent development models into account. Furthermore a general approach will be described for the development processes based on the product's life cycle.

3.2.3 Key Decisions

Andreasen [1986] and Clark [2001] use key decisions in their models to support the development process. These key decisions are made at the end of each process element. While both authors use the same number of key decisions they are located at different places in the concurrent development process. However, each core discipline must adapt the decision made at each decision point to their individual product. Figure 3.2.3-1 provides the comparison of the key decisions.

	Process element 1	Process element 2	Process element 3a	Process element 3b	Process element 4	Process element 5
Andreasen [1986]	Need for the Product	Product Principles	Preliminary Product		Fully Specified Product	Product as Sold
Clark [1993]	Concept Approval	Program Approval	Detailed Design Approval	Joint Product and Process Approval	Approval for first Commercial Sales	Full Commercial Approval

Figure 3.2.3-1: Comparison of key decisions

Cooper [2001] defines these kinds of decisions as gates or gateways. Gates or gateways serve as quality-control checkpoints that allow developers to decide at predefined decision points whether to 'go forward' to the next stage, 'rework' the current stage to find an acceptable result, or to 'stop (kill)' the project at the current stage.

3.2.4 The Core Disciplines

In this thesis, concurrent development is used as a systematic approach to the integrated development of discrete products and their related processes. A basic requirement for concurrent development is teamwork. A team performs better than the sum of the specialised individuals. A successful development team needs the right functional composition of specialists. The composition of each team depends again on the expertise required to support the process of that part of the product life cycle for which the team assumed responsibility [Prasad, 1996]. A concurrent development team is composed of a number of specialists, who work together in a parallel manner to meet the overall goal. The three previously described concurrent development models in chapter 3.2.2, as well as Roozenburg [1995] and Scallan [2003] agree on the following three core disciplines:

- Marketing & Sales
- Product Development
- Production Development

These three disciplines represent the core disciplines of a concurrent development process. All the disciplines are equal, and no single discipline dominates. All core disciplines support the concurrent development process to reach the overall development goal.

3.2.5 Development Processes in the Product Life Cycle Process

The Concurrent Development Model (CDM) orientates its timeline on the product lifecycle. The product lifecycle describes the period from the beginning of a product idea to the end of the product, which nowadays is more or less the recycling of the product. As a base for determining the chronology and their activities of the product lifecycle the thesis uses the models from Usher [1998], Asiedu [1998], Alting [1993] and defined the following phases:

- Need Recognition
- Product Initialisation
- Concept Development
- Detailed Development
- Realisation
- Production and Distribution
- Retirement and Disposal
- Recycling

The recognition of the need for a product usually initiates the start for every new product. The reasons can be manifold and depend on the prevailing circumstances. On the one side internal needs can occur, such as the search for new product ideas or new technologies for future products. On the other side the need can be stimulated externally. For example the customer needs have to be translated into product ideas or a market survey may produce a new product idea. At the end of the need recognition phase a gateway evaluates the ideas economically and technically.

Since need recognition is actually not directly part of the development process so it will be not considered further in this thesis. The following four phases, product initialisation, concept, detailed development and realisation, are the main development processes.

With the end of the realisation phase the product and the production facility has the maturity to pass on into the Production and Distribution phase. By that, the main developing activities end and the regular production activities start. Before the Start of Production (SOP) Product and Production Development were the major disciplines during the development process. After SOP the Production Department takes over the responsibility for operating the production facilities. Additionally, marketing & sales takes over the responsibility for the distribution and sales of the product in this phase. Nevertheless, the product and its production facilities have to be developed further and undergo Continuously Improvement (CI) activities. During this CI-process the Product and Production Development are involved to support these activities as experts in the team. Even if the support decreases with the progressing to End of Production (EOP) it should never stop. After EOP, Retirement & Disposal and Recycling are the last two phases of the product lifecycle. A support of the core disciplines of the Concurrent Development Model (CDM) is not necessary any more. However, despite the fact that the core disciplines are not present in the last two phases, the recycling of the product and production can be considered of the beginning of a new development process.

3.2.6 Processes of the Integrated Product Development

Andreasen [1986], Clark [1993] and Ulrich [2000] provide a concurrent development process model describing development processes valid for all core disciplines. The latter two divide the process into five individual processes. Andreasen [1986] proposes an additional process, which is carried out prior to the initiation of the actual development process. This step is designed to distinguish whether the perceived need arises from an unsatisfactory situation or a business opportunity. Andreasen [1986] illustrates this as a single cloud covering all three core disciplines. Clark [1993] divides the process element ‘Detailed Design and Development’ into two phases. In the first phase he focuses on the verification of the product design and equipment, and in the second on the verification of process design, including product refinement. Figure 3.2.6-1 summarizes all three authors’ development processes.

	Andreasen [1986]	Clark [1993]	Ulrich [2000]
Process 0	Recognition of Need		
Process 1	Investigation of Need	Concept Development	Concept Development
Process 2	Product Principle	Product Planning	System – Level Design
Process 3	Product Design	Detailed Design and Development	Detailed Design
Process 4	Production Preparation	Commercial Preparation	Testing and Refinement
Process 5	Execution	Market Introduction	Production Ramp-Up

Figure 3.2.6-1: Comparison of process

3.2.7 Process Elements of the Core Disciplines

Clark [1993] and Ulrich [2000] describe development process elements in a quite general manner with respect to each core discipline and each process element. Andreasen [1986] describes process elements more abstractly and places greater emphasis on the process flow among elements.

The three authors describe the Marketing & Sales process elements differently in terms of the level of detail and the chronological order in which the process elements should be carried out. In general, Marketing & Sales maintains contact with the customer. At the beginning of the development process, this discipline identifies and formulates customer specifications and develops a preliminary marketing plan. As the product takes shape, the marketing plan becomes more detailed and the customer is asked for feedback to improve the product. Finally Marketing & Sales promotes the new product and introduces it with an advertising campaign and market rollout.

Product development as a core discipline focuses on product design. According to Andreasen's [1986] approach, the "recognition of need" signals the start of a new product. Clark [1993] and Ulrich [2000] begin immediately with product idea and concept development. Feasibility investigation and prototype testing assist in completing these early process elements. In the following step, the product structure is defined and alternative solutions are evaluated. The most successful solution is chosen for detailed design and subsequent testing. Results and insights from the tests are used for product redesign and improvement.

Production development is the step where the production process and its equipment are designed. The three authors differ on the required task sequence. The first step involves identifying the necessary processes as well as make or buy determinations and manufacturing cost estimations. Next, production principles are investigated and determined. After these elements have been decided, the production processes and equipment are designed in detail and partially tested in pilot units. The experience gained from the pilot tests helps to improve the processes and the equipment. The final step concludes when the production plant is prepared and ramped up.

Besides the three mentioned authors, numerous other authors describe the development process elements for a single core discipline. The most relevant for this thesis are as follows. Kotler [2003] is often cited in the area of Marketing & Sales, in which he describes marketing process elements during development from different points of view. Scallan [2003] emphasizes the importance of sales process elements at the end of the development process. Pahl [1995] is well known for his contributions in structuring the product design process with various process elements and activities. Hubka [1976] placed product development under the umbrella of technical systems and French [1985] makes contributions to product development process elements during conceptual design, while Hansen [1976] describes a systematic product development process and Roozenburg [1995] gives a good example of a list of process elements related to the product design in industrial engineering. The VDI 2221 [1987] lists process elements and activities for a general development approach to technical applications in the field of mechanical engineering. Wu [1994] also provides a list of process elements, but focuses more on manufacturing system design. More detailed descriptions of production development process elements and activities are provided by Eversheim [1982] and

Spur [1994]. Both authors use a sequential approach. Scallan [2003] and Swift [2003] describe a sequence of process elements for process design, which is seen as a part of production development. Russel [2003], Vonderembse [1996] and Reid [2002] provide good examples from the field of operation management, where production development process elements are described and important activities are illustrated.

3.3 Project Management

Traditionally, the development of production lines and cells for discrete products was embedded sequentially within the product development process [Eversheim, 1997], [Spur, 1984]. The production development process was characterized by applying specific engineering tools, such as capacity or workforce planning in a repetitive manner. In the 80's and 90's the market changed towards more product variety and novelty [Thurner, 1993]. Manufacturing environment shifted to lower total product volumes and more product flexibility paired with shorter development time. Consequently, each new production facility has become a fast, dynamic and unique undertaking. The question now arises, whether production development fits the new manufacturing environment or whether a new scientific aspect has to be considered, such as project management which is a well proven tool to achieve specific goals for such a unique undertaking [PMBOK, 2000], [Field, 1998], [Rolstadås, 2001]. Project management focuses on time effectiveness and enhancing product quality. Unfortunately, literature does not provide a connection between production development and project management. This chapter aims to give an overview of traditional project management and its characteristics as well as its application in product development.

3.3.1 Traditional Project Management

Projects are a common task in engineering design. Traditionally project management was applied in situations where the target market and the technologies were relatively well understood. Consequently, models have been developed which minimize the changes once a product has been designed [MacCormack, 2001]. These models are well researched and commonly applied and will therefore be used as a basis for this thesis.

A project is a "one of a kind" task with a clearly defined goal to be reached within a given time and cost frame [Rolstadås, 2001]. A project aims to achieve a beneficial change and therefore carries considerable risk and uncertainty and uses a separate project organisation. Project management is a system-orientated approach to management, because it considers the project as a system of interrelated tasks and work units operating in a changing environment [Nicolas, 2001].

To carry out a project means to manage five different objectives: scope, organisation, quality, time and costs [Thurner, 1993]. The first two objectives are mandatory, since there will be no project without a scope and an organisation is needed to carry out the project. Quality, time and cost are desirable objectives and their importance depends on the specification of the project, see figure 3.3.1-1.

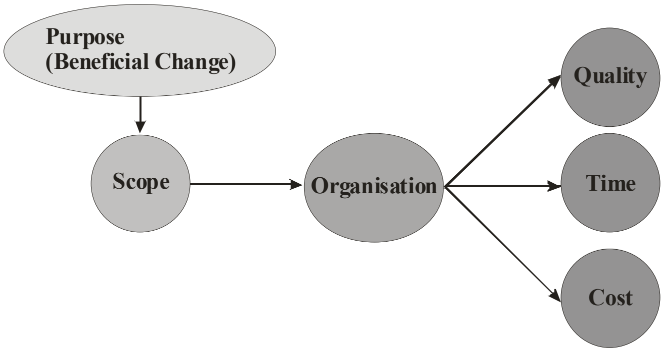


Figure 3.3.1-1: The five objectives of project management

The objective scope ensures that only the work is undertaken, which is necessary to achieve the projects purpose and to achieve beneficial changes. The next objective is the organisation which allocates the adequate and necessary resources (human, material, financial). Time, cost and quality are driven by the objective scope and the organisation and are a constraint to the project [Thurner, 1993].

It is a fact that every project carries a certain amount of risk. Not considering the risk very early on the project can have drawbacks or even ruin the project [Nicolas, 2001]. The source of risk is the uniqueness of the project. But, in a repeating production environment the risk can be reduced to a very low level. Risk itself is in general a function of its likelihood and impact. Now, a project can be considered risky, when at least one of the factors is large. To handle risk properly the discipline of risk management has to be applied.

Project management is the management of change, but explicitly planned, from the initial concept with the change directed towards the unique creation of a functioning system. General or operations management also involves the management of change, but in this case the purpose is to minimise the effects of change on an already developed system [Smith, 2002].

To distinguish projects from operations, a project has to fulfil the following seven requirements [Smith, 2002]:

1. Defines a single, definable purpose or end item (product or result)
2. Unique. A project requires doing thinks differently than before. A project is a “one of a kind”
3. A temporary activity. Once the projects goals are achieved, the project ceases to exist
4. Utilizing skills and talents from multiple professions and organisations.
5. Possibly unfamiliar. It may encompass new ideas, technology, approaches and process elements of significant uncertainty and risk.
6. There is something at stake. Failure may jeopardise the organisation
7. The process of working to achieve a goal.

Even through a task can be defined as a project, it might sometimes still be inappropriate to use project management tools and techniques.

Cleland and King [1983] suggest five criteria to help to decide when the application of project management is appropriate:

- Unfamiliarity
- Magnitude of the effort
- Changing environment
- Interrelatedness
- Reputation of the organisation

Every project is process orientated and can be viewed as a four-stage process, which represents the project management life cycle [Thurner, 1993], [PMBOK, 2000], [Rolstadås, 2001]:

- Project Initiation
- Project Definition
- Project Execution
- Project Close-out.

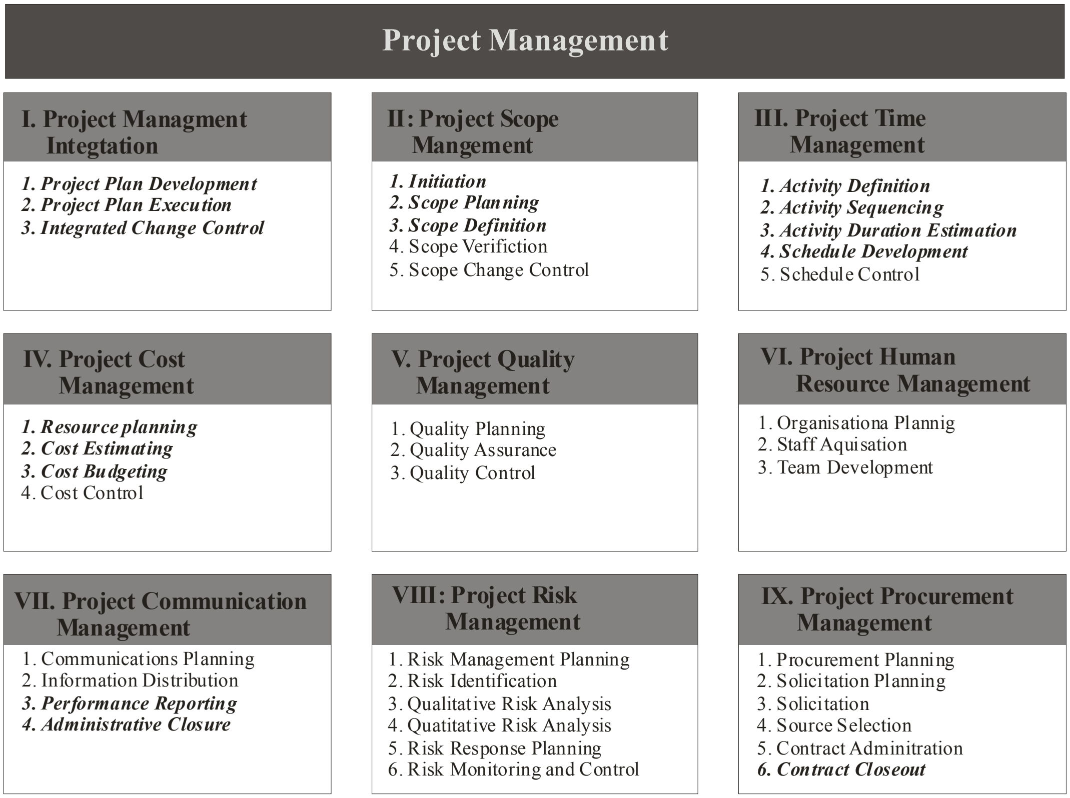
The duration of these project phases vary from project to project, and delays sometimes occur between the stages. These phases can also overlap. Nevertheless, the phases are linked by the results they produce and thereby the output of one process is often the input of the next process

The Project Management Institute (PMI®) published the PMBOK® guide in 2000 [PMBOK, 2000]. The primary purpose of this book is to describe and identify generally accepted project management bodies of knowledge and is a basic reference addressed to all professions including project management. To achieve a PMBOK® the PMI® has first formed nine knowledge areas:

• Project Integration Management	describes the process required to ensure that the various elements of the project are properly coordinated.
• Project Scope Management	describes the process required to ensure that the project includes all the work required, and only the work required, to complete the task successfully.
• Project Time Management	describes the process required to ensure timely completion of the project.
• Project Cost Management	describes the process required to ensure that the project is completed within the given budget.
• Project Quality Management	describes the process required to ensure that the project will satisfy the needs for which it was undertaken.
• Project Human Resource Management	describes the process required to make the most efficient use of the people involved in the project.

• Project Communications Management	describes the process required to ensure timely and appropriate generation, collection, dissemination, storage, and ultimate disposition of project information.
• Project Risk Management	describes the process concerned with identifying, analysing and responding to project risk.
• Project Procurement Management	describes the process required to acquire goods and services from outside the performing organisation.

Secondly, all these nine Body of Knowledge areas can now be broken down in terms of their component processes, see figure 3.3.1-2. All these processes are further divided into core processes and facilitating processes. Core processes have clear dependencies performed in essentially the same order in any project. Facilitating processes are interactions among the other processes and are more dependent on the nature of the project. Although these processes are performed periodically it does not mean they are optional. The core processes are illustrated in bold in figure 3.3.1-2.



Project Management

I. Project Managment Integtation
1. Project Plan Development
2. Project Plan Execution
3. Integrated Change Control

II: Project Scope Mangement
1. Initiation
2. Scope Planning
3. Scope Definition
4. Scope Verifiction
5. Scope Change Control

III. Project Time Management
1. Activity Definition
2. Activity Sequencing
3. Activity Duration Estimation
4. Schedule Development
5. Schedule Control

IV. Project Cost Management
1. Resource planning
2. Cost Estimating
3. Cost Budgeting
4. Cost Control

V. Project Quality Management
1. Quality Planning
2. Quality Assurance
3. Quality Control

VI. Project Human Resource Management
1. Organisationa Plannig
2. Staff Aquisation
3. Team Development

VII. Project Communication Management
1. Communications Planning
2. Information Distribution
3. Performance Reporting
4. Administrative Closure

VIII: Project Risk Management
1. Risk Management Planning
2. Risk Identification
3. Qualitative Risk Analysis
4. Quatitative Risk Analysis
5. Risk Response Planning
6. Risk Monitoring and Control

IX. Project Procurement Management
1. Procurement Planning
2. Solicitation Planning
3. Solicitation
4. Source Selection
5. Contract Adminitration
6. Contract Closeout

Figure 3.3.1-2: Overview about the Project Management Knowledge Areas [PMBOK, 2000]

The body of knowledge are performed in processes. All these processes can again be organised into five process groups [PMBOK, 2000], namely:

Initiating processes:	authorizing the project or phase
Planning processes:	defining and refining objectives and selecting the best of the alternative courses of action to attain the objectives that the project was undertaken to address
Executing processes:	coordinating people and other resources to carry out the plan
Controlling processes:	ensuring that project objectives are met by monitoring and measuring progress regularly to identify any variance from the plan so that corrective action can be taken if necessary
Closing processes:	formalizing acceptance of the project or phase and bringing it to an orderly end.

These processes are liked by their result. These connections are illustrated in figure 3.3.1-3.

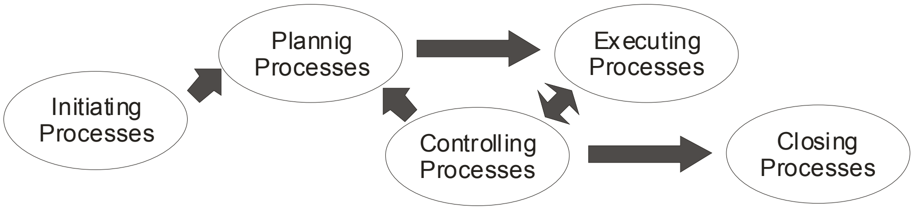


Figure 3.3.1-3: Links among the process groups in a phase [PMBOK, 2000]

All five process groups are carried out in each phase of the project life cycle. Thereby the level of intensity alters from phase to phase. In each process group the different categories of the bodies of knowledge are applied and linked. Due to this relationship the different process groups and bodies of knowledge interact. By concentrating on these links, each project management process can be described in terms of input, tools and techniques and output. Finally the nine categories of the BOK, their components, and the process interaction are combined into a detailed process map showing all necessary processes, their inputs, outputs and tools. This map can now be used as a guideline for all projects. The detailed project management map for all phases is provided by the PMI® [PMBOK, 2000].

3.3.2 Project Management and Product Development

For the majority of engineers, project work is a way of life throughout their professional career [Dorf, 2000]. Project management is widely applied in an industrial setting and one typical application is product development [Thurner, 1992], [Andreasen, 1986], [Nicolas, 2001]. Designers often work in their own environment where planning, controlling and managing of the product realisation is an inevitable part of a successful product development process. The creation and control of the design process is part of what can be called managing design [Dym, 2000]. Literature about project planning and control deals only to a limited extent with product development [Andreasen, 1986]. He further emphasises that product development has to take place on the terms of the project and not on the terms of the organisation.

The basis for the application of project management in product development is the product life cycle. Distinct tasks can arise from the product life cycle, such as production development or general engineering design. The nature of these tasks can differ from other project management applications. Product management demands a flexible structure to establish an innovative and creative environment. The organisation must be versatile and adaptable in their approach depending on their circumstances [Dym, 2000]. It involves individuals with special skills from various functional disciplines. A difficulty can be the scope definition. Often designers do not have a detailed idea of the final result before they are way into the project. Overall, the special characteristics of product development need to be taken into consideration in project management. A holistic example of product development management is presented by Armstrong [2001]. An example for breaking down the product development process into concurrent engineering templates is give by Ulrich [2000], Clark [1993] and Andreasen [1986].

A direct connection between project management and production development has not been documented. However, Curtis [1988] connects very briefly process planning and project management and suggests a 23-step WBS structure for process planning. He recommends the critical path procedure to estimate the time required for planning the whole project process.

3.4 Multidisciplinary Industrial Teams

As described in chapter 3.1 production development is carried out within a concurrent setting and that requires a multidisciplinary team. The goal of this chapter is to focus on the most important aspects of industrial teams in relation to production development. Aspects of industrial teams are described in many ways by numerous authors. Since this thesis focuses on production development in networks, this chapter will describe first in a general manner what types of teams exist, how they can perform, what kind of leadership is needed and the various roles in teams and how teams carry out their primary problem solving and decision making. The chapter will then focus on the characteristics of the overall product development teams, since no connection between production development and development teams was found in literature. Finally, the role of the supplier and its dimension of involvement in the development team will be described and possible connections to the customer's organization.

3.4.1 Team Characteristics

A team is a group of persons, who collaborate and join their efforts to reach a common goal effectively. Teamwork occurs in a form where people meet and work together to reach agreement and solve problems. The advantage of a team in product development has been recognised for quite some time [Andreasen, 1986], [Chase, 1998], [Womak, 1990], [Imai, 1992], [Clark, 1993], [Shina, 1994], [Ulrich, 2000]. The reason for this is on the one hand, that most products have become so complex in recent years that the development process cannot be handled by a single person or single department. On the other hand, it is assumed, that a team can perform better than the sum of its individual team members [Donnellon, 1990], [Henke, 1993]. Multidisciplinary teams, encouraged by the concurrent engineering philosophy, have become the basic organisational element in product development.

3.4.2 Type of Industrial Teams

Industrial teams can be described in many different ways. One way to distinguish the form of teams is how they appear in an organisation. Aranda [1998] used the following distinction:

- Work Teams
- Task Teams
- Management Teams

Work teams are natural work groups within an organisation. The teams develop from a natural work environment as in departments or units. Aranda [1998] emphasises, that this type of team exists more as a collection of individuals than as a team. It is possible, that the members have different or even contradicting goals. The team members are often coming from the same department or function. The advantage of this team is that it can provide quick and efficient solution in the functional area of the team members. All members know and understand the work processes of the other team members. A disadvantage is that these teams draw boundaries around their responsibility and focus on internal issues and efficiencies.

Task teams are different and by definition temporary [Aranda, 1998]. Task teams are usually cross functional and come into being to get as many ideas as possible about a given specific problem. This type of team does not have such an impact on the organisation since it does not need extra management. However, task teams are not without problems. Two major difficulties are the valuing of other perspectives and managing implementation. Often different perspectives lead to conflict and single team members tend to protect their own interests. Success is often viewed as the best result for their own interests. Furthermore it is difficult to get acceptance of the found ideas from outsiders. Heavy resistance repeatedly kills an idea before it is implemented, which has a deep impact on the team’s motivation. Therefore it is necessary to consciously design the team’s power level and mix of the team members. Furthermore it is important to clearly specify the task and the time commitment required of each team member.

Management teams have the least obvious purpose and are often not sure why the team is coming together. A management team creates its own goals, which all team members are responsible for. The goal setting often refers to an enhancement of the communication within an organisation regarding work, problems or achievements. The management team tries to inspire and integrate the work of the organisation. This work usually comprises of building a vision, refining the culture, carrying out major change initiatives or improving the image of the organisation.

It can be summarised, that an industrial team appears in three different ways in an organisation. Therefore an organisation is not fixed on one type but can use all three types in one organisation at the same time. Nevertheless, to establish a successful team the differences within and among the teams must be emphasized.

Another way to describe an industrial team is according to their level of performance. The studies of Katzenbach [1993] resulted in four different categories of teams, see figure 3.4.2-1:

- Pseudo Team
- Traditional Team
- Cooperative Team
- High Performance Cooperative Team

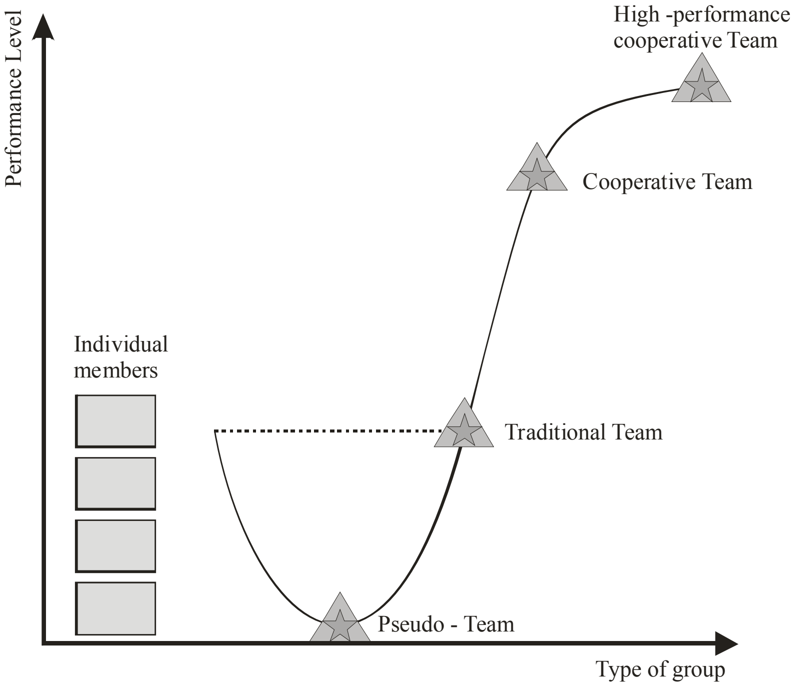


Figure 3.4.2-1: Performance level of different types of groups [Katzenbach, 1993]

The members of the pseudo team have no interest in working together. The team members are competing and are rivals. This results in interference and blockage so that the team would perform better, if each member would work alone. The members of the traditional group are assigned to tasks, which do not interfere. For structured assignments no joint efforts are necessary. The team members seek information, but are not motivated to share freely their own information. So, the performance is similar to the performance, as if each team member was working alone. Cooperative team members are assigned to the same goal. Their success depends on the collaboration of all team members. The result is, that the team members work together face-to-face, share information, excel their team skills and share responsibility for providing leadership. High performance cooperative groups outperform all expectations of cooperative groups. It is different to the former type of group in its level of commitment. To achieve an innovative output from the team it is important to recognise the team process.

3.4.3 The Team Process

Just putting together a group of people and expecting immediate results will result in the failure of the team. A success criterion to understand is that a team moves through a set of stages and needs to develop a team process in order to perform successfully. There exist many approaches to a team process in literature. The following common five-step approach is presented by Tuckman [1965]:

- Forming
- Storming
- Norming
- Performing
- Adjourning

In the first stage the team members get into contact and start to work together. In the storming period the members get into conflict and differences appear. During norming the conflict and differences are managed and solved. The actual work is carried out during the performing stage. After the goals are reached the team dissolves.

Aranda [1998] suggests a different three-stage process, which can be carried out in a cycle:

- Formation
- Developing
- Renewal

During formation the team decides on the task, its goal and agrees on the basic rules to achieve the goal and how to behave within the team. In development, the focus is on building cohesion and strengthening the team. Conflicts are resolved and the team members start to identify with the team. Following, these norms are created and the team starts to perform well. The goal of development is to create an environment where the freedom to explore and to change mindset becomes natural. In renewal the team evolves and pushes itself beyond the limit. The result is that the team becomes high performance. In the last stage of renewal the team transforms. The team is very creative in problem solving and results are produced. But the team is also at its limit and a transformation, i.e. restructuring or disbanding, is necessary to get an even higher team performance.

It can now be seen, that a team needs a certain amount of time before it starts to solve problems successfully. This is different from experts, where results can be expected much quicker. Further the team needs time to disband, so that the team uses only a certain fraction of its time for valuable creation. The management, when assigning a task to a team, must consider this. And if the team is inexperienced with the team process it will need outside guidance or it will never reach the performance stage.

3.4.4 Roles and Leadership

A team is a fundamental work unit in the company's organisation. However, not every team is led the same way and even within an organisation the roles and leadership of team members can change. One aspect of leadership is developed in a historical content, where teams are traditionally supervisor led and evolve over the years into a self-led team. Today, both kinds of team are applied depending on the situation. Conner [2001] states, that we would like to think, that teams could always be self-managing, but at times, particularly in the early stages of team development, it is important to identify someone who will be charged with certain responsibilities. Therefore, leadership can be provided from the outside of the team or from the inside of the team.

Conner [2001], Aranda [1998] and Armstrong [2001] give a good insight into this aspect of leadership and state, that the traditional leadership from the outside can cause many problems. If the manager is too passive it is very likely, that anarchy will lead the team. The team will feel lost, takes inappropriate actions, and will have a lack of responsibility and there will be no goal setting. Furthermore the team will probably look after problems the organisation is not interested in. If the manager is too active, the team will feel heavily controlled which will lead to a loss of motivation and creativity. Another difficulty is the acceptance of a solution. If the solution is rejected, the team will loose again its motivation. In the case of many rejections the team will start to fight against the management's integrity and the organisation. The team will disintegrate and will no longer be of value to the organisation. All in all, the situation will then become worse than without teams.

To overcome this dilemma leadership from the inside was introduced. This is based on the realisation that the team needs empowerment. The team is given the control and the team is in charge. As a consequence the team needs a team leader from the inside, whose strategy issues are the same as the organisation's issues. This strategy shall bring order to the team. Again if the team leader is too passive the team will loose focus, performance and creativity. If the team leader is too active, the team members will feel too much control. Either extreme is unproductive. The introduction of a facilitator was one solution [Conner, 2001], which ensures that the interest of the company and the needs of the team members and leader are met.

Today, effective teams carry out their own leadership role. These teams are called self-led teams. The leadership role is often achieved from roles and responsibility when carrying out an assigned task. The team needs support and guidance but can take care of its own tasks. Its team members will share the responsibilities and tasks. This enhances the communication and the decision-making process in the team and the team can now manage its internal culture and external relationships.

Self-led teams are quite efficient, but teams can also be very efficient having not reached the level of being self-led. However, this assumes a good relationship with the leader outside the team and with the organisation. Aranda [1998] illustrated in a four-level model the behaviour of a team during the transformation from an organisation-led to a self-led team:

- *Level 1: Goals and objectives given*; chair designated; chair directs action
- *Level 2: Goals given, objective developed*; leadership from within; internal focus; static

- *Level 3: Direction given; goals developed*; shared leadership, facilitator used; team reaches out; grows
- *Level 4: Team understands organisational strategy*; has resources; shared leadership; external focus

Independent from the leadership of the team has every participant one or more distinct roles. It might be a technical role as an expert or a functional role. Three functional roles have been already mentioned in the former text, namely a team facilitator, a team leader and a team member. Their role is characterised by the following responsibilities [Armstrong, 2001]:

- Team Facilitator:
    - Organise the logistic of the assigned task including planning appropriate activities
    - Communicate the activity and the goals of the activity to the appropriate people
    - Conduct training; ensure the task is clearly understood
    - Assist the team in keeping focus
    - Mediate conflict resolution pertaining to the activities.
    - Oversee goal attainment
- Team Leader
    - Lead the activities of the team during the duration of the assigned task
    - Conduct regular communications to facilities management
    - Coordinate resources during activity
    - Track and follow up on open items after the activity
- Team Member
    - Empowered, self-directed, ownership – team is responsible
    - Balanced, consensus decision making
    - Establish and maintain the work plan
    - Establish team and ground rules
    - Working sessions and formal team meetings
    - Reviews and approves drawings and other design documents
    - Process improvement
    - Status reporting

3.4.5 Decision Making and Problem Solving

Problem solving and decision making in a team is a far too large research field to be described in this thesis in all aspects, although the motive for gathering people in a team is the solving of an exiting problem and effective decision making. Consequently, decision making and problem solving should belong to one of the core competencies in a team. To provide a sufficient introduction into that topic, the author has decided to focus on two aspects of decision making: (1) The *type of decision* and (2) the *decision making process*.

Aranda [1998] illustrates in a matrix the four major types of decisions, see figure 3.4.5-1. A major misunderstanding that teams have is that each problem has the same decision process. This matrix helps depending on the problem to choose an appropriate decision process.

The upper left corner covers the decisions within minor tasks. These are short-term decisions with minor impact, which are often made on a daily basis. The critical point is that the decision should be made fast in order to move on to more important decisions. Time can easily be wasted if the team discusses the problem too long. The upper right field deals with the minor decisions relating to people or to the organisation. Time is again critical for these kinds of decisions.

		Focus	
		Task	People
Impact	Minor	**Requires decision but has no lasting effect on the team or organisation** *Time frame: fast* *Quality: Acceptable* *Thinking: Primarily procedural* Process: 1. Identify issue 2. Review facts 3. Consider choices 4. Decide 5. Move on	**Important to individual but relatively unimportant to organisation/team** *Time frame: fast* *Quality: Consistent* *Thinking: Procedural with some construct* Process: 1. Identify issue 2. Consider current policy 3. Consider impact on other 4. Decide 5. Communicate decision and rational
	Major	**Has long-term implications for the organisation/team** *Time frame: Moderate* *Quality: Accuracy and acceptance* *Thinking: Constructed supported by procedural* Process 1. Identify issue 2. Gather comprehensive information 3. Search for options 4. Evaluate options a. Consistent with goals b. Possible side effects 5. Consult those affected 6. Decide 7. Advise those affected 8. Follow up during implementation	**Has impact on entire work group** *Time frame: Long* *Quality: Involvement and acceptance* *Thinking: Primarily constructed* Process: 1. Involve those affected 2. Gather information on fact and feeling 3. Develop options 4. Consider options carefully a. Consistent with values and principles b. Possible side effects 5. Decide 6. Communicate clearly and widely 7. Follow up with learning and development

Figure 3.4.5-1: Team decision making matrix [Aranda, 1998]

The team will decide on small assignments, attendance, team recommendation, which all have an impact on the organisation. Most of these decisions are already stated in the company's policies and practices. Therefore the thinking is mostly procedural. Since these decisions involve people, the consideration of impact on others in very important. The lower quadrants show decisions with a major impact. On the left side the decisions are related to the team's task, such as major equipment, investments, design evaluation or change management. Since a wrong decision has a major impact, the focus is on the quality of the decision. The thinking style needs to be constructed and supported by procedural components. It should be noted, that creativity is a major driver in searching for options and should thereby be a major competence within the team. The last quadrant deals with the decisions that have a major impact on the people in the organisation. Examples are mergers, restructuring, lean manufacturing or the change to a team-based organisation. These decisions need to have a clear thought process and the best solution is often not the right answer. It is the acceptance and involvement that is the key to the success.

Another important aspect in team decisions is provided by Johnson [1991], who sets the decision in relation to the level of involvement of the team member in the decision. The author describes the following seven methods:

1. *Decision by authority without discussion:* The leader makes all decisions without consulting the group
2. *Expert member:* The most expert members are allowed to decide for the group
3. *Average of members' opinion:* The group's decision is based on the average of group member's decision
4. *Decision by authority after discussion:* The leader makes the decision after discussion with the group
5. *Minority control:* Two or more team members, but less than 50% of the group, make the decision by representing an executive committee or a special problem-solving group
6. *Majority control:* Decisions is made when more than 50% agree with the solution
7. *Consensus:* Consensus is achieved, when everybody in the team agrees with the solution

The quality of the decision rises from the first methods up to "consensus", which is probably the most effective method. But with the rising level of involvement the time needed to make the decision rises as well. Thus, in order to make an effective decision a compromise between time and quality has to be found.

Problem solving is the other crucial task of teams mentioned in this thesis and needs a proper strategy. An often used and well known strategy is the Deming Cycle, which was originally known as the Shewhart cycle during the 1930's [Deming, 1982], [Scholtes, 1990], [Imai, 1992]. This cycle represents a dynamic model and helps a team or a single person to analyse the problem and find a solution. The process is carried out on four steps namely: (1) *Plan* (2) *Do* (3) *Check* (4) *Act*, see also figure 3.4.5-2.

The first step is "Plan". In this step the problem is selected and analysed. It is necessary to determine the root of the problem, define it clearly and to write a problem statement. This statement should also include a measurable goal for the problem solving effort. During the "Do" step the criteria for a solution is selected. The team generate potential solutions and decide on the solution, which addresses the root cause of the problem best. The solution is then implemented on a trial run, a prototype or a simulation. The "Check" step verifies the results. Data from the conducted test are gathered and evaluated against the goal setting from step one.

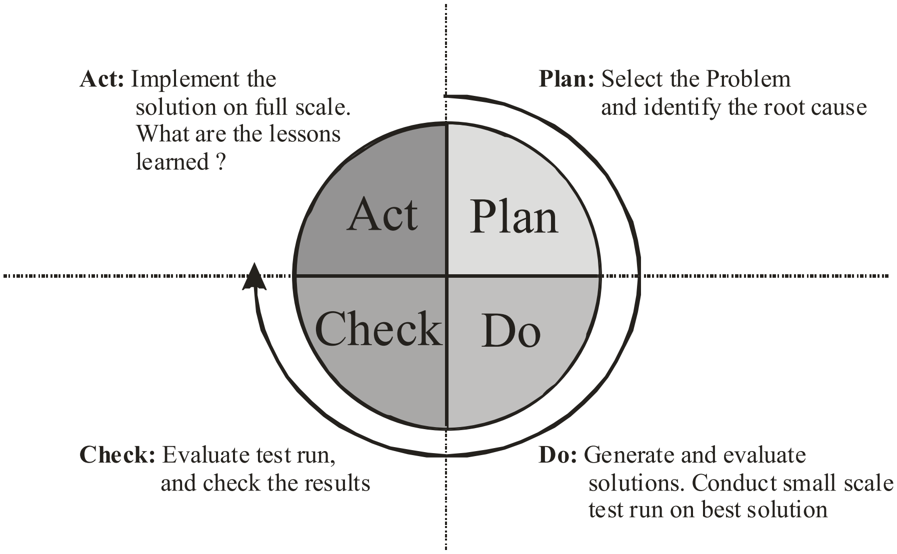


Figure 3.4.5-2: The Deming Cycle

If the results are as expected the solution is standardized in the “Act” step. Thereby, the team identifies the necessary systematic changes and training for a full implementation. This implementation needs constant monitoring by the team and is an opportunity to search for new problems. However, if the solution does not meet the desired criteria the “Act” step is skipped. Instead it is required to start the PDCA Cycle all over again and come up with some new ideas for solving the problem.

3.4.6 Multifunctional Teams in Product Development

So far, aspects of industrial teams have been described as independent from the industrial sector and its goals. This thesis focuses on concurrent development of production lines and facilities for the discrete goods producing industry. The development of production lines and facilities is part of the overall concurrent product development process, as mentioned in chapter 3.2. A connection between production development and teams is not described in literature. Therefore, the overall product development team in a cross-functional setting is viewed in greater detail. Product development teams are the basic element of concurrent product development [Andreasen, 1986], [Clark, 1993], [Prasad, 1996], [Hauptman, 1999], [Ulrich, 2000], [Kušar, 2004]. Koufteros [2001] suggests that one of the most useful forms of lateral communication in product development situations, where joint efforts are across multiple functional departments, is the multifunctional team. Concurrent product development strives to combine the interest of all development functions so that the final product meets the customer’s needs and is realistic in terms of the capability of the manufacturer and its supplier [Nicolas, 2001]. The coordination among the departments with multifunctional teams will then enable the organisation to assign tasks with a high level of interdependence [Hauptman, 1999].

In product development, multifunctional teams had their breakthrough in the 90s’. They have proven more creative, less problem ridden and faster in finding a solution

[Donnellon, 1990], [Henke, 1993]. Dröge [2000] found out, that multifunctional product development teams are a consistent predictor to minimize new product development time. Karlsson [1996] emphasises multifunctional teams as a basic supporting factor for lean product development. These benefits are achieved by working across functions and gather all employees working on the same project. Henke [1993] suggests that firms realise four primary benefits through the use of cross-functional team:

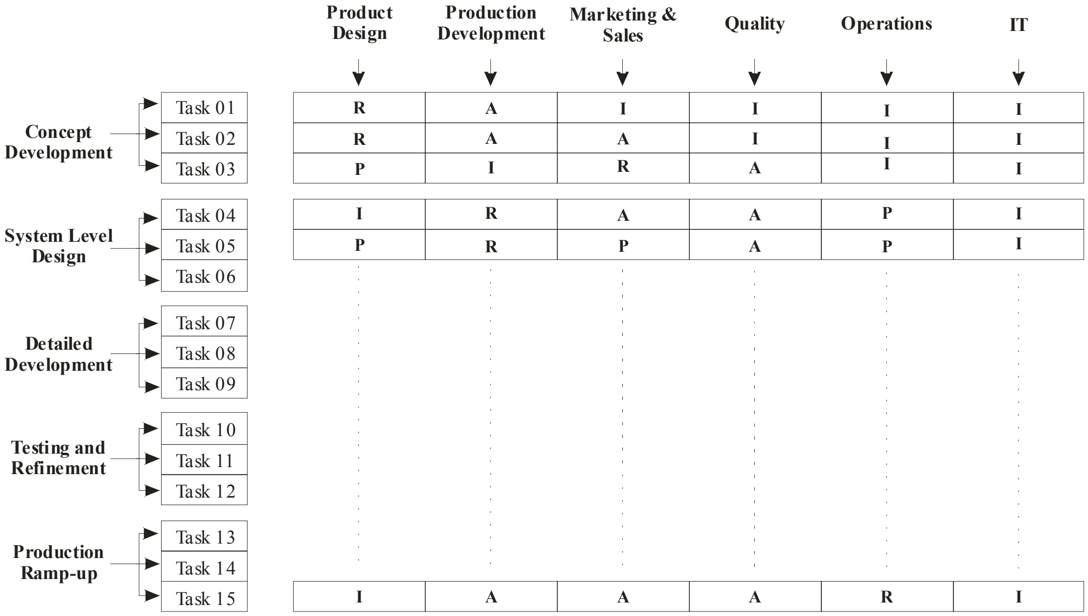
1. The shortcomings of hierarchical structures are overcome by the team's ability to cut across traditional vertical lines of authority
2. Decision-making is decentralized (lateral decision process)
3. Hierarchical information overload is reduced at higher level
4. Higher quality decisions can have significantly greater potential of occurring than with individual decisions

As described earlier in this chapter Aranda [1998] introduced three types of team: (1) *work team*, (2) *task teams* and (3) *management team*. In SMEs work teams present the product development team, since there are not enough resources available to shuffle the team for each new project. This teamwork is rather difficult. Team members will have problems understanding the work of outside departments or companies and will probably follow their own individual goals. Even blaming the other team members for the existing problem can occur and all team members will then be more reluctant to suggest new solutions. It is apparent; that the multifunctional team based on the work team needs a much longer time to establish itself and additionally needs active coaching. Task teams are by nature multifunctional and temporary. Product development uses multi-functional work teams in order to be capable of handling the complete development process. This type usually represents a product development team in larger companies. The team stays together for the given task and then disbands. In large projects a core team is always present and invites different functional areas into the project as it moves from development stage to development stage. Management teams are not typical product development teams and therefore not considered further.

Independent from the development type, teams should be organised for the best control over the product decision and facilitating of intra team communication and commitment. Nicolas [2001] lists the following conditions, which affect considerable the performance of the development team:

- Autonomy of the team
- Full time assignment of the team member
- Collocation of the team to work in close proximity and share one office
- Small size of the team with maximal 10 to 20 members
- Team of doers, with each member a specialist on own area willing to share common responsibilities and obligations

The basic characteristic of a product development team is its functional composition and the responsibility of the team members and leader. The right selection of the team member, leader and facilitator is very important for the success of the team. However, the product development team is embedded into an organisation and is not really independent and self-contained. The team interacts with the surrounding organisation and the choice of resource it interacts which is as crucial for the success of the team as the functional composition [Henke, 1993]. Choosing now the team members, it is not enough to invite all functional areas right from the beginning but better to invite the single function when required. Additionally a core team should be established representing the development functions: product design, production development and marketing & sales [Andreasen, 1986], [Clark, 1993], [Ulrich, 2000]. To get this organisational issue structured it is recommended that the team sets up a responsibility matrix showing the Work Breakdown Structure (WBS) of each product development stage and the development functions, see as an example figure 3.5-1. Thereby it is useful to distinguish between the responsibilities, for example according to *(R) responsible, (A) must give approval, (P) participate and (I) be informed.*



		Product Design	**Production Development**	**Marketing & Sales**	**Quality**	**Operations**	**IT**
Concept Development	Task 01	R	A	I	I	I	I
	Task 02	R	A	A	I	I	I
	Task 03	P	I	R	A	I	I
System Level Design	Task 04	I	R	A	A	P	I
	Task 05	P	R	P	A	P	I
	Task 06						
Detailed Development	Task 07						
	Task 08						
	Task 09						
Testing and Refinement	Task 10						
	Task 11						
	Task 12						
Production Ramp-up	Task 13						
	Task 14						
	Task 15	I	A	A	A	R	I

Figure 3.4.6-1: Responsibility matrix

The product development process now becomes transparent and should be distributed to each function in the development process. The different responsibilities are clearly assigned to each function and the project manager is able to determine the needed human resource. However, product development is a creative and innovative task and it is often not clear in the beginning which path has to be followed. It will be difficult to determine all the required tasks right from the beginning. Therefore, the responsibility matrix must be continuously updated and communicated to all involved parties.

3.4.6.1 Supplier Involvement in Product Development

It is widely accepted, that supplier involvements directly into the product development team yields in more efficient products [Deming, 1982], [Womak, 1990], [Clark, 1993], [Katzenbach, 1993]. Today, the picture of a stand-alone company that is linked to its customer and suppliers only by delivery and procurement of products is not longer valid

[Wiendahl, 2002]. The motives for building networks are manifold [Maffin, 2001]. Firstly, the market is getting more competitive and as a result the product is getting more complex. The customer demands among other things products of higher quality, shorter lead-time and reduced costs. It is therefore widely accepted that product development needs a concurrent approach with multi-disciplinary activities. But since there are an increased number of process technologies, companies are often not able to develop the needed technology and experts in-house. As a consequence suppliers have gained more and more importance and responsibility in their customer's product technology especially in product development [Maffin, 2001]. These suppliers no longer compete for orders based on cheap labour but with advanced engineering skills, equipment and short lead times to the final customer [Chang, 2002]. Therefore suppliers also have a strong impact on product and production development times and efficiency [Swink, 1996], [Karlson, 1996]. Consequently, it is necessary to incorporate outside suppliers into the multifunctional product development team as active and participating members [Henke, 1993]. This incorporation should be shown in the responsibility chart shown in figure 3.4.6-1. Hillebrand [2004] emphasises that because the internal cooperation is influencing the success of external cooperation by functioning as a coordination mechanism, managers need to include internal cooperation in the design of the firm's external interfaces

The cooperation between the product development team and the external partner is changing with the progress of the product development process. Fraser [2003] describes several types of collaboration throughout the development process and illustrates the cooperation during development as partnerships and consultancies, see figure 3.4.6.1-1.

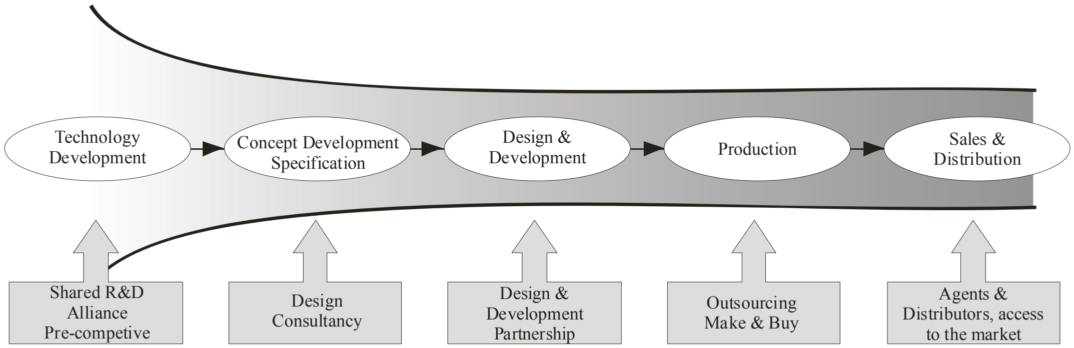


Figure 3.4.6.1-1: Types of external cooperation in product life cycle stages [Fraser, 2003]

Thereby, the decisions about the level of outsourcing and make & buy of components and services are already made in the early design stages and thus, the foundation for the future cooperation is already planned. How this cooperation is structured in detail is not described by Fraser [2003]. In summary, the rational for external cooperation is to exploit the suppliers' investments, innovations and specialized professional capabilities [McCarthy, 2004]. This enables the product development team to reduce development costs, whilst achieving an increased focus on its own core competencies.

In order to choose an appropriate cooperation with an external partner in product development it is important to decide on two strategic issues, namely the dimension of the supplier involvement and the coordination strategy. Both issues will be described in the following sections.

3.4.6.2 Dimensions of Supplier Involvement

Lakemond [1999] describes three dimensions of supplier involvement: (1) *task characteristic*, (2) *degree of involvement* and (3) *moment of involvement*. The task dimension describes the level of novelty of the product development project. Novelty is defined by the extent to which new technology rather than exiting technology is needed and the complexity of the components of the new product. A three step task characteristic is suggested by Lakemond [1999] as (1) *incremental*, (2) *next generation*, (3) *radical*.

The degree of involvement refers to the amount of responsibility transferred to the supplier. The more competitive the supplier is, the higher can be the degree of involvement. Hartley [1997] suggests three types of supplier responsibility ranking from low to high, namely (1) *Buyer Development:* Low or no supplier involvement, (2) *Shared Development:* Supplier and buyer share development, (3) *Supplier development:* Complete development by suppler. The latter supplier's responsibility is also known as "Black Box Engineering", where the supplier carries out most of the development tasks.

The moment of involvement describes the stage in the product development process, when the customer begins to search for a suitable supplier and make them aware of the project. A key factor indicating the depth of the internal and external cooperation is at what stage the supplier selection decision is made [McIvor, 2004]. The resulting type of cooperation is already illustrated in figure 3.4.6.1-1. McIvor [2004] and Lakemond [1999] describe three possible moments of involvement in the product development project. The first moment is in the early development stages. Here the supplier influences the new product to a high degree with engineering consultancies, contributing to the design expertise or suppliers provide input to complete components. The second moment is during the detailed development phase. The supplier is responsible for complete product components or provides black box designed parts. The third possible moment is in the product integration phase. The manufacturing knowledge becomes important and suppliers, such as toolmakers, equipment manufactures or process specialists, have a very important role in ramp-up the production facility.

3.4.6.3 Coordination Strategy

Another important strategic issue is the coordination between supplier and customer. Lakemond [1999] illustrates in her work four different kinds of coordination which manage different kinds of supplier dependency, see figure 3.4.6.3-1. In cases of a necessary low dependency a direct designer contact is chosen. If the dependency is higher it is more likely to choose an organisational form similar to the sub-problem coordination or the project integration coordination.

The bureaucratic control is a hierarchical organisational form, where the contact between the supplier and buyer takes place on a high organisational level. This form is preferred in case of contractual issues. The direct designer contact appears, when the designer from the buyer has a direct contact with the suppliers' designer. This communication is on an operational level and contact is only made if a question about the project arises. This contact requires a relationship between the organisations that has similar expectation, norms and goals. This relationship must be accepted by both organisations.

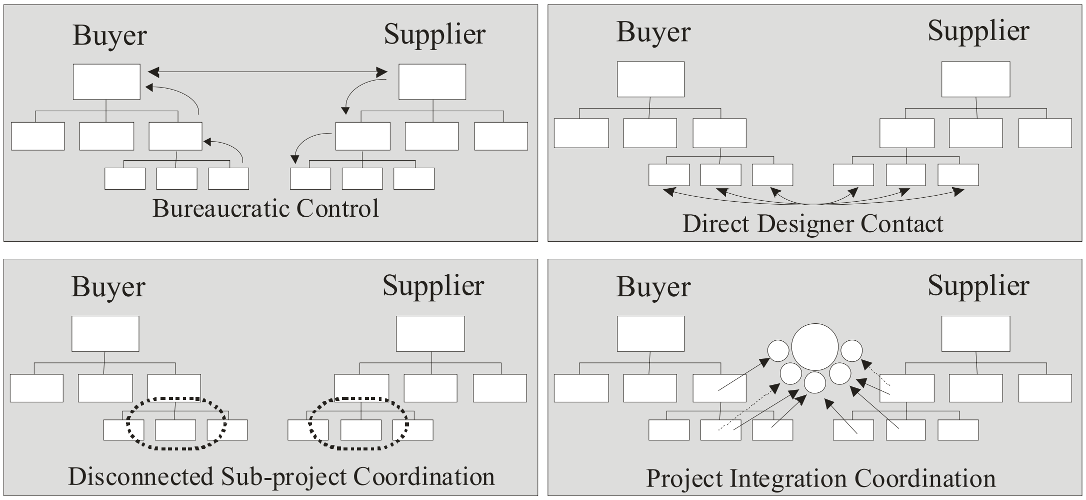


Figure 3.4.6.3-1: Supplier coordination strategies [Lakemond. 1999]

In disconnected sub-project coordination the supplier carries out the task almost independently from the buyer's organisation. The supplier will create its own project within its own organisation. Thus, the interdependency of both parties is relatively low and therefore requires high task independency. Furthermore, this organisational form needs fewer communications and interactions between both parties. However, this demands an excellent product requirement list and extensive communication at the beginning of the project. In project integration coordination the supplier is an active member of the development project. All tasks are carried out together with the buyer's organisation. Often the engineers of the supplier's organisation are sent out as resident engineers to the product owner. However, the team need not be sitting in one room; geographical distances can be overcome by many tools and technologies, such as video conferences or virtual factories. And all team members carry their own set of experiences and expectations contributing to the overall goals. This also suggests that a minimum set of common expectations must exist [Lakemond, 1999].

3.5 Tools and Technology in Development

To perform the different production development tasks several tools and technologies are necessary and available. This chapter describes the tools and technology listed in literature which can be used for production development or are adapted from the adjoining fields of project management and multidisciplinary teams.

3.5.1 Definition

It is essential for the production developer's work to use the right working methods to achieve the desired results. In general all working methods used can be categorized into tools and technologies in order to separate the working methods that have influence on the product and those that have influence on the efficiency on the production development process. Therefore, the following definitions are made in this thesis:

> ***Tools*** *are working methods which have the goals to enable the production developer to carry out the task and to optimize its output.*
>
> ***Technologies*** *have the means to drive the production development process to more efficiency in terms of time, cost and quality.*

Tools and technologies are an essential part of each step in production development. They are a mechanism applied to the input to create the output [PMBOK, 2000], see figure 3.5.1-1. Thus, to achieve results from the different production development steps the production developer needs to have an appropriate toolbox.

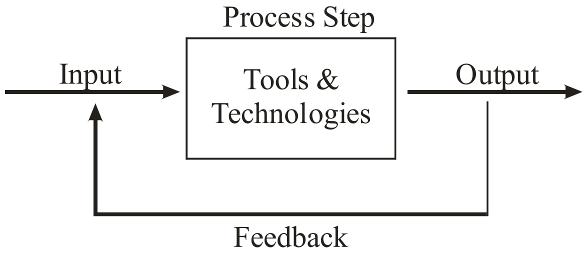


Figure 3.5.1-1: Tools and technology

The array of application for tools and technologies are as manifold as they are stated in literature. They help to determine the customer's wishes, targets and manage different phases of the production development process. The task of the production developer is to select and apply the right tool from his toolbox for any production development process. A generally accepted method for the selection of the correct tools and technologies and how to use them in the right manner is not described in literature.

In this thesis several different engineering areas are screened for their contribution of tools and technologies to production development. In the following sections the major tools and technologies of production development are described. Also the tools and technologies of project management and supporting multidisciplinary team work are listed which can be used in production development.

3.5.2 Production Development Tools and Technologies

Production Development is defined as the interface between product design and regular production and deals with the planning and industrialization of new discrete products in new production cells or lines. It consists of a set of engineering tasks embedded in a production development project, see chapter 3.1.1.

To carry out these tasks literature suggests many tools and technologies. A first very important step toward a successful production facility is that of process planning. During process planning the production tasks are determined to produce the planned product. A basic tool to determine the different production processes is flowcharting. Flowcharting is in general a graphical illustration of the flow of activities and information of a process. Flowcharts exist in many different forms and differ in symbols representing the different processes, such as manufacturing processes, transport, storage or decision, activity and documentation. An overview of commonly used flowcharts as well as cross functional and multileveled flowcharts can be found in Anderson [1999] and Meyers [2000]. Special application is the production flow chart using the ASME symbols operations, transport, inspection, delay and storage, see [Krajewski, 2005], [Slack, 2004], [Russel, 2003]. Another commonly used flowchart to represent the manufacturing process is the IDEF methodology [Prasad, 1996], [IDEF 2004]. An overview of alternative symbols than from ASME is listed in Spur [1994]. Using these symbols, assembly flow charts, manufacturing flowcharts and operation process charts can be established and further analysis and optimisation carried out. A further development of the flowchart is value stream mapping using predefined symbols to illustrate a production or a design flow. It takes the extended value stream from the supplier to the customer into account; see also Rother [1999] and Tapping [2002].

Other resources of process determination are experts and databases. Databases are stored “Best Practice” or experience from last production development project. The databases can be used by the production developer when required to use past experience of internal and external standards and designer guidelines. Experts are a human resource, with a special knowledge or training. Experts are guided by historical information which should be used whenever possible. If such expertise is not available, the estimates can be inherently uncertain and risky [PMBOK, 2000].

Having a process map enables the production developer to determine the individual production processes and equipment. A comprehensive methodology is presented by Swift [2003]. The PRIMA selection strategy includes process capability charts for most of the manufacturing process. Scallan [2003] presents an overview of the different types of production equipment, such as tooling selection or workholding devices. Both methods have the use of guidelines and experience in common, as described above.

Additionally Scallan [2003] and Swift [2003] mention the importance of using DFA and DFM methods as a tool to optimise the product-process compliance. The objective of DFA is to identify product concepts which are inherently easy to assemble and to favour product and component designs that are easy to grip, feed, and join and assemble by manual or automatic means [Syan, 1994]. DFA guidelines are gained from designer’s experiences and are collected over a long period. Generally, these rules take the form of samples lists with no framework or systematic guidance for their application [Syan, 1994]. The aim of these guidelines is to alert the designer to consider certain features in the design process. Design for assembly guidelines are listed in Boothroyd [1994], Corbett [1991] or Andreasen [1988]. Another well developed tool is the House of Assembly originated by Rampersad [1993]. The DFA house is made for analysis and redesign of the product’s structure and the related assembly processes. To facilitate the DFM process, the institute for product development in Denmark introduced a „Seven Step DFM Procedure“. This procedure is an approach aims to turn the current design to a more sophisticated design [Fabricius, 1994]. Olsen [1992] suggests seven evaluation dimensions called Universal Considerations. All products have consequences in all these dimensions, whether they are considered or not. DFM guidelines are another resource as a systematic tool, of global nature and gained through empirical research. Stoll [1990] created a list of thirteen general guidelines. Typically, this tool facilitates systematic application of DFM knowledge in the form of codified statements of guidelines and rules. Summarizing it can be said, that DFA and DFM using tools such as procedure, guidelines and checklists.

Having established the production process it is very important to determine the possible failures and risks. In order to review the design, tools such as the failure mode and effect analysis (FMEA), fault tree analysis (FTA) or the value analysis (VA) can be used [Russel, 2003].

The FMEA procedure is a tool for a systematic approach to determine failure modes. Applying the FMEA on the manufacturing process is called Process FMEA. This procedure is almost formalised. All failure modes can be ranked and addressed one by one to reduce the production solutions risk. The complete FMEA can be carried out in a methodical way supported by worksheets. Drozda [1988] shows an 11 step procedure, similar to VDI 2247 [1994]. Both authors present PFMEA worksheets and guidelines. In contrast to this the PFMEA priorities failures and attempts to eliminate their causes, the fault tree analysis emphasises the interrelationship of failures [Russel, 2003]. Failure and causes are listed in a tree using symbols for “or” and “and” nodes to determine acceptable und unacceptable solutions, see also Russel [2003] or Slack [2004]. Value analysis helps to detect unnecessary features and function. Thereby every component is subject to certain questions; see also Mudge [1971], Russel [2003] or Krajewski [2005]. For every component a team determines a function and a value. The ratio of cost to value can be used to find the unnecessary functions and features.

Most production developments tools and technology can be applied with computer support. Computer support helps to store huge amounts of data and make the data access easier and faster. By that the information flow is supported and complex production facilities can be visualized more transparently. So, lead times and costs can be decreased and development quality and flexibility can be increased [Eversheim, 1997]. Computers also support simulation, such as a digital factory or FEM simulations. Realistic simulation early in the design process enables the production developer to recognise risks and failures and implement design changes rapidly.

Part of production development is the planning of internal transport of materials, products or people. The process flow chart is the basis for this, where the transport and storage is already determined. No special tools or technology could be found, for planning the transport equipment, such as tubes or containers, in relation of production flow. However, Meyers [2000] gives an overview of available and common transport equipment.

Layout planning is the arrangement of the physical equipment in economical activity centres, which are needed by a facility’s various processes. In order to gain a layout, several tools are suggested. One possibility is the use of existing guidelines and databases of existing layouts see Krajewski [2005], Russel [2003]. Furthermore group technology, procedures, templates, tape techniques and mathematical evaluation parameters can be used to choose the right design, see Meyer [2000]. All authors mention the support of computer software, such as CAD, 3-D modelling or digital factory software.

To meet the requirement constant monitoring of the production process capability is needed to. The production developer will identify the most appropriate quality assurance tools and techniques to be employed. Thereby the quality planning tools determine the inspection location, testing methods, their frequency, evaluation of data and the identification of appropriate data [Scallan, 2003]. He chooses seven basic tools to accomplish these development tasks: process flowcharts, check sheets, Pareto diagrams, histograms, cause-effect diagrams, scatter diagrams and SPC charts. Russel [2003] identifies the same tools and states that these are the most popular ones for quality related issues. A principle procedure for quality planning with guidelines can be found in Eversheim [1997]. The PMBOK [2000] uses quality planning methods for projects, namely cost/benefit analysis, benchmarking, design of experiments and cost of quality. Cost of Quality is not mentioned in the other screened literature and refers to the total costs to achieve the required product's quality.

Apart from the factory layout the workstation has to be designed for the machine-operator interface. Workstation design describes the result from ergonomics and workstation layout. Ergonomics is the science of preventing injuries caused due to the workplace. Health and safety is considered in the workstation design. Meyers [2000] and Slack [2004] suggest that for the workstation design you should use tools such as guidelines, procedures, checklist, experts or databases. Furthermore exits industrial standards, governmental regulations and laws for ergonomics. I.e. for light requirements or anthropometric and neurological aspects exist.

Human resource planning in production development deals with the determination of the necessary number and qualifications of the operators and their necessary training. Eversheim [1997] presents a procedure with guidelines. This procedure gets the resource needed from the choice of the organisational forms in manufacturing. Russel [2003], Meyer [2000] and Slack [2004] use time study tools to determine the necessary human resources, such as stopwatches, motion studies, analytic sampling and activity sampling. All these methods follow a procedure with a mathematical evaluation. The qualification is developed from the job description with the help of analogy of other job descriptions, databases or creative methods, such as brainstorming. Special tools to train operators are not mentioned in the screened literature.

Developing production facilities need to include the determination of manufacturing, investment and tooling costs. Manufacturing costs are an essential part of a successful design and are often used for decision making. Dubbel [1990] and Scallan [2003] illustrate a cost breakdown structure for manufacturing costs as a tool. Comprehensive mathematical tools can be found in Dondrup [1997] and Heinen [1985]. For investment and tooling costs, tools such as analogies, benchmarking, experts, analytical forecasting methods and financial ratios are suggested.

Suppliers play an important part in the development and manufacturing process. Suppliers can contribute in the form of services and physical components. A central tool mentioned in literature for the decision of as to whether components or services can be outsourced is the make/buy decision. A flowchart with decision points is given by Scallan [2003]. A make/buy checklist is presented by Russel [2003] and the author lists the analytical hierarchy process for ranking the supplier solutions and evaluation.

Krajewski [2005] used the break- even analysis as a tool to evaluate whether services or components can be outsourced. Further mentioned is the use of experts, standards or industrial databases.

Prototype support comprises of the assistance of the product design department with the technical expertise of the production developer. Additionally the production developer contributes to the evaluation of the prototype testing. Literature did not show that a common tools or technologies for the production developer exist.

Production development projects are complex tasks, which create a huge amount of data and paper. A PDM (product data management) system manages and stores product design, manufacturing and support data [Eynard, 2004], which are often also required by industrial or governmental regulations. This technology helps the production developer to manage both the product data and the production data. A PDM system is a software system [Armstrong, 2001]. It aims to reduce development costs through better access to data and faster communication; for more details, see Armstrong [2001].

Apart from tools and technologies supporting a single task of the production design process, there exist generic tools and technologies which claim to support the production development process. Commonly known is Quality Function Development (QFD), it is a tool to translate the customer’s requirements into technical requirements, using procedures and algorithms [Akao, 1992]. Don Clausing [1994] enhanced the traditional model up to four linked matrixes including the component development, the process planning and the operational requirements. Thereby he created the possibility for the production developer to translate the design requirements into manufacturing requirements early in the development process. Suh [1990] developed with axiomatic design a mathematical method for production development. The mapping from the physical domain to the process domain results in the design of the manufacturing process. However, this tool is not very well described in literature and the main problem with its application in reality is that it is not always possible to plot the physical domain against the process domain. Vallhagen [1996] concludes that this method is, in some aspects, still insufficient for designing manufacturing systems.

3.5.3 Project Management

A project is a “one of a kind” task with a clearly defined goal to be reached within a given time and cost frame [Rolstadås, 2001]. To carry out a project means to manage five different objectives: scope, organisation, time cost, quality [Thurner, 1993]. Production development is carried out in projects and it is assumed, that the general scope is determined before starting production development and the responsibility for organisational issues lies outside the production developer’s competence, see chapter 3.3. It follows, that the project management technology used to reach the objective time, cost and quality can also be used in production development. However, the PMBOK [2000] presents a detailed process orientated view about project management, where technologies from the objectives organisation and scope can be used. Some general technologies for setting up the process for production development can also be used. In the following sections the results of technologies found in common project management literature will be discussed, in particular from Thurner [1993], PMBOK [2000], Nicolas [2001], Smith [2002], Armstrong [2001] and Eisner [2002].

One objective is to manage time, which has to be estimated, communicated and controlled. Time in a project context describes the duration of the work elements and the network to calculate the overall project duration. The technology used to determine the duration of each work element is estimation, which depends on the real amount of work and waiting time. This method needs an expert and a checklist to include all the various types of times. All these elements can now be set together to yield the total duration of the project. Basic mathematical network technologies are the critical path method (CPM), the program evaluation and review technology (PERT) and the precedence diagramming method (PDM). These networks can be established with the help of the activity-on-node (AON) and the activity-on-arrow (AOA) tools. In the case of restricted resources, resource loading technologies are available. A more advanced technology is the graphical evaluation and review technique (GERT), which utilizes the probabilistic and branching activity nodes. Tools to communicate the schedule are activity listings and bar charts; a common used example is the Grant Chart. For more complex systems computer supported technologies can be used. Controlling the time schedule can be done by using charts, guidelines and statistical tools, such as resource histograms.

Another big focus in project management is on cost budgeting, estimation and control. Supporting technologies of cost planning are done to classify work tasks and cost, expert opinions and top-down structure. Cost estimation can be carried out with parametric, analogy estimates or mathematical methods. Examples given in literature are step accounting, exponential, functional or elemental methods. Further guidelines and standards can be used listing the different types of cost components which have to be considered. For illustrating costs in a project, cost breakdown structures and time-based network graphs can be used. Another well known tool is the earned value analysis (EVA), a formal procedure used for estimating costs and schedule variance of a project and forecasting them to the end of the project.

Achieving good quality in a project means first to assure the quality and later to control it according to the master quality plan. The literature suggests ensuring the quality on the project level a stage-gateway process with design reviews is necessary. Gateways and design reviews are essential technologies to ensure that the stakeholder requirements are met. Also other technologies are mentioned, such as experts, historical data, standards, norms and guidelines. In controlling the quality and variation from the quality plan, technologies are available in form of check lists, audits, reports, supervision, test and demonstration, benchmarking and analogies. Another important aspect of quality is controlling the project’s changes. Changes are inevitable in a production development project. The advised technology of handling changes is a formalized procedure based on design freezes. This process, often called engineering change request, is supported by guidelines, decision boards, standards, forms, checklists, logbooks, and predefined procedures. A developed technology for controlling and tracking changes is configuration management.

Apart from the common technologies addressing specific objectives of a project, another technology is available, which can be used in the production development process. This technology is the SWOT analysis. A SWOT analysis is an instrumental framework to identify the Strengths, Weaknesses, Opportunities and Threats for a particular project. Strengths and Weaknesses are internal value creating (or destroying) factors such as assets, skills or resources. They can be measured using internal assessments or external benchmarking. Opportunities and Threats are external value creating (or destroying) factors a company cannot control. This technology can be applied at the beginning of the production development process to determine strategic aspects.

Another interesting source for project management technologies is the Project Management Body of Knowledge Guide [PMBOK, 2000]. It describes project management knowledge that is generally accepted. The project management process is divided into phases of the different BOKs. Chapter 3.3.1 illustrated the correlation between the PMBOK and production development and lists a number of phases describing the production development project. Each phase is described with an input, output and technology; see list below:

- Project Integration Management
    - *Project Plan Development:* Project planning methodology, Stakeholder skills and knowledge, Project management information system, Earned value management
    - *Project Plan Execution*: General management skills, Product skills and knowledge, Work authorisation system, Status review meetings, Project management information system, Organisational procedures
    - *Integrated Change Control*: Change control system, Configuration management, Performance Measurement, Additional planning, Project management information system
- Project Scope Management
    - *Scope Definition:* WBS templates, Decomposition
    - *Scope Verification:* Inspection
    - *Scope Change Control*: Scope change control, Performance measurement, Additional planning
- Project Time Management
    - *Activity Definition*: Decomposition, Templates
    - *Activity Sequencing*: Precedence, Arrow and conditional diagramming method, Network templates
    - *Activity Duration Estimation*: Expert judgement, Analogous estimation, Quantitatively based duration, Reserve time
    - *Schedule Development*: Mathematical analysis, Duration compression, Simulation, Resource levelling heuristics, Project management software, Coding structure
    - *Schedule Control*: Scheduling change control system, Performance measurement, Additional planning, Software, Variance analysis
- Project Cost Management
    - *Cost Estimation*: Analogous and bottom-up estimation, Parametric modelling, Computerised tools
    - *Cost Control*: Cost change control system, Performance Measurement, EVM, Additional planning, Computerised tools
- Project Quality Management
    - *Quality Planning*: Benefit/costs analysis, Benchmarking, Flow charting, Design of experiments, Cost of quality
    - *Quality Assurance*: Quality planning tools and technologies, Audits

  - *Quality Control:* Inspection, Control charts, Pareto charts, Statistical sampling, Flow charting, Trend analysis
- Project Communication Management
  - *Communication Planning*: Stakeholder analysis
  - *Information Distribution*: Communication skills, Information retrieval system, Information distribution systems
  - *Performance Reporting*: Performance review, Variance analysis, Trend analysis, EVA, Information distribution technologies
  - *Administrative Closeout*: Performance reporting, Project reports, Project presentation
- Project Risk Management
  - *Risk Monitoring and Control*: Risk response audits, Periodic risk reviews, EVA, Technical performance measurement, Additional risk response planning
- Project Procurement Management
  - *Procurement Planning*: Make/buy analysis, Expert judgement, Contract type selection
  - *Solicitation Planning*: Standard forms, Expert judgements
  - *Solicitation*: Bidder conferences, Advertising
  - *Source Selection*: Contract negotiation, Weighting and Screening system, Independent estimates
  - *Contract Closeout*: Procurement audits

3.5.4 Multidisciplinary Team Work – Decision Making

Production Development is carried out in a multidisciplinary setting. In this section a summary of the technologies is presented, which can be used to support the different aspects of team work. In particular the aspects of creativity, problem solving, responsibility, conflicts in teams and decision making are highlighted.

Production development involves a creative process. Creativity is the basic process in development that can react quickly and inventively through generating ideas and developing these into more useful ideas [Lamik, 2001]. This enables an organisation to see new development projects more as a challenge than as a threat. Literature suggests many technologies that support creativity. Lamik [2001] states, that there exist at least 250 technologies. Roozenburg [1991] divides creativity technologies into three categories: (1) association technologies, (2) creative confrontation technologies and (3) analytic-systematic technologies. Association technologies, i.e. brainstorming, encourage spontaneous reaction to ideas expressed earlier. Creative confrontation methods create connections of ideas, which were not related originally. This is the chance to gain completely new, unexpected combinations. Analytic-systematic technologies use an analysis and systematic description of the problem, to achieve a solution to the problem, i.e. a morphological chart.

Krohe [1996] reviewed more than 4000 articles on creativity and found the following 22 major creativity technologies; see list below:

- Analogies and Metaphors
- Boundary examination,
- Brainstorming
- Crawford blue-slip writing
- Bug list technique
- Brain writing
- Attribute association
- Manipulative verbs
- Morphological forces connections
- Disjoined instrumentalism
- Decomposable matrices
- Left /right brain alternations
- Goal/wish
- Interrogatories
- Force field analysis
- Lotus blossom technique
- Nominal group technique
- Problem reversal
- Progressive abstraction
- Wildest ideas
- Wishful thinking.
- Peaceful setting

A generic tool on how to choose between the technologies is not stated in literature. Team orientated production development needs problem solving technologies. Roozenburg [1991] presents a generic formalized method to problem solving, which is based on the characteristic that the solution is not tried out in reality. A commonly accepted tool is Deming's problem solving cycle that represents a dynamic model and helps a team to analyse the problem and find a solution, see also chapter 3.4.5. Problem identification is a commonly mentioned field in literature and technologies are mentioned which can be used in production development. Most of these technologies are either statistical or graphical tools. The most mentioned statistical technologies are the scatter diagram, histogram, bar chart and the Pareto chart [Russel, 2003], [Slack, 2004], [Stevensen, 2005]. Another well known graphical technology is the cause effect diagram also known as the fishbone or Ishikawa diagram. Another technology addressing the whole problem solving process is the Root Cause Analysis (RCA). The RCA is a structured step by step technique that focuses on finding the real cause of a problem and deals with that, rather than continuing to deal with its symptoms [VBM, 2004]. Also well known is the process failure mode and effect analysis (PFMEA) which is a problem identification and evaluation technologies, which has already been mentioned earlier in this chapter.

Production development is a project and the team needs to be organised. Tasks and responsibilities need to be assigned to each team member. A good graphical technology is the responsibility chart, which assigns responsibilities to each team member, independently from internal and external resources [Thurner, 1993], [Dym, 2000]. The PMBOK [2000] lists also technologies regarding team work in their own category:

- Project Human Resource Management
    - *Organisational Planning*: Resource practice, Templates, Organisational theory, Stakeholder analysis
    - *Staff Acquisition*: Negotiation, Pre-assignment, Procurement
    - *Team Development*: Team building activities, Management skills, Reward and recognition system, Collocation, Training

Conflicts in teams are an inevitable part of any running production development project and can develop into a thread for the team. To resolve conflicts Eisner [2002] refers to conflict styles as an analysing technology. Smith [2002] presents a methodological conflict analysis technology and guidelines for confrontation and negotiating a conflict. Armstrong [2001] suggests guidelines, for example, openly discussing all disputes, confining disputes in order to handle conflicts. Further he recommends using a "stakeholder map" to resolve conflict by partly reorganising the project.

In production development the decision making process can be made in the team. An overview about decision making in teams was already given in chapter 3.4.5. Aranda [1998] presents four types of decision and presents a step-by-step methodology for each of them. Roozenburg [1991] lists multi-criteria technologies to evaluate the best design from the alternatives. He separates design decisions into ordinal and cardinal technologies see list below. It is assumed, that these decisions are made under certainty, which means that the evaluation factors are not uncertain.

Ordinal decision technologies

- The majority rule
- The Copeland rule
- The rank-sum rule
- The lexicographical rule
- The datum rule
- New product profile

Cardinal decision technologies

- The weighted objective method
- The additive value function
- Measuring effectiveness
- Estimating the weight factors

A general methodology for decision making can be found in Smith [2000] and Roozenburg [1991]. Both authors use the methodical approach to guide the designer through decisions.

4 Discussion

In chapter 3 production development and its adjoining fields of project management, integrated product development, multidisciplinary teams and engineering tools & technologies were presented as stated in literature. The goal of this thesis is to decrease development time in SMEs by providing a methodology for a better understanding of the production development process. To get a comprehensive view of production development it is important to screen the upper mentioned adjoining fields so as to isolate their individual role and contribution to production development. In this chapter the author discusses and analyses these different scientific fields mentioned in order to find their single contribution to production development.

4.1 The Role of Production Development in Integrated Product Development

The objective of this section is to examine the network of core disciplines involved during concurrent development and to make a chronological investigation of the different phases in order to gain a common view. In this chapter the different components of a concurrent development process model (CDPM), as stated in chapter 3.2, will be determined, detailed and visualized in a process matrix.

4.1.1 Components of the Concurrent Development Process Model

The SCOR reference model V5.0 [SCOR, 2003], as described in chapter 3.2.1, can be used to describe and structure the concurrent development process on different levels. This reference model consists of four levels. The highest level corresponds to the process, the second level to the process elements, the third level the tasks, and the fourth level the activities. Chapter 3.2.2 described how concurrent development models have significant similarities to the level two and three of the SCOR model, see chapter 3.2.1. Additionally, Andreasen's [1986] and Clark's [1993] CDM models include key decisions that must be made after each process element. The importance of the key decisions is also mentioned in the project management literature, see Armstrong [2001]. It can now be said, that the elements of a concurrent development model can be ranked as followed:

- the core discipline
- the key decisions
- the development process
- the process elements of different core disciplines

4.1.1.1 The Core Disciplines

One basic requirement for concurrent engineering is teamwork. It is more or less based on the simple fact, that a team can have a better performance than every individual. But this performance peak cannot be achieved by just putting numerous people together. A key issue for a successful team is its functional composition. The composition of each team depends on the expertise required to support the process of that portion of the product life cycle for which the team has assumed responsibility [Prasad, 1996]. One aspect of the team's functional composition is the capability of the team during the product development process. During this particular stage of the product life cycle several authors, such as Ulrich [2000]; Andreasen [1986]; Chase [1998], have agreed on the three basic functional capabilities, which all product development processes have in common:

- Product development
- Production development
- Marketing and sales

All these functional capabilities represent the core disciplines of the concurrent development process. There is not one major core discipline; moreover, each core discipline is a support function for the overall development goal. Additionally to these core functions exists more support disciplines, such as human resource or accounting. These disciplines can be demanded if required.

4.1.1.2 The Development Process

Andreasen [1986], Clark [1993] and Ulrich [2000] each present in their research work a sequence of processes. The processes described in chapter 3.2.6 were first analysed and placed into chronological order as shown in figure 4.1.1.2-1. The context for this approach was the work content of each process element as described by each of the three authors, rather than the actual process names.

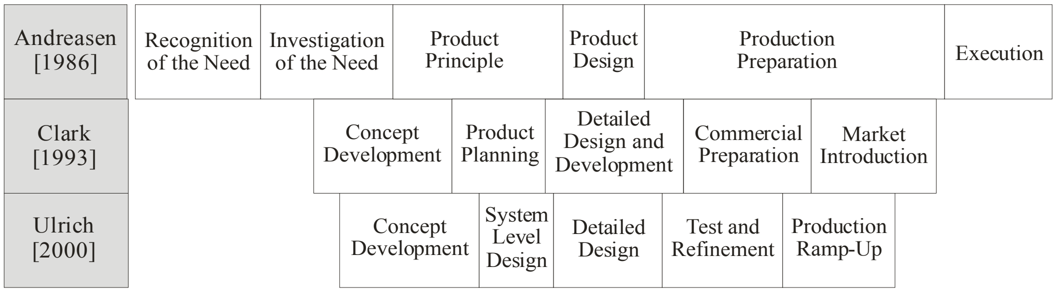


Figure 4.1.1.2-1: Comparison of process phases

Figure 4.1.1.2-1 shows that there is very little agreement between the three authors with respect to the concurrent development process duration and the content of the processes. This means that a common view based solely on the processes listed by the three authors cannot be achieved.

To obtain a common view of the development process, the tasks of each core discipline must be analysed and placed in relation to a neutral development cycle that can be valid for all discrete products. All discrete products must pass through a product lifecycle. Such an approach allows for the possibility of using the product lifecycle as a neutral reference for the concurrent development process. The product lifecycle is described as a sequence of several processes that the product must pass through from its origins up to its disposal. Additionally, a neutral scale for a commonly accepted concurrent development lifecycle has the advantage of structuring the entire engineering process. Based on literature surveys, presented in chapter 3.2.5, and the lifecycle models the following process elements of a product lifecycle were identified:

- Need Recognition
- Product Initialization
- Concept Development
- Detailed Development
- Realization
- Production & Distribution
- Retirement & Disposal
- Recycling

Not all processes of the product life cycle are necessarily a part of the concurrent development process. Need Recognition is a part of the preparation for the main development process, which includes all subsequent process elements up to and including Realisation. At the end of the Realisation the product is fully developed and its production has been approved according to predefined requirements. In Production & Distribution the product and production process will be further developed with respect to special details within the scope of the continuous improvement (CI) process. During the CI-process, the same cooperation between the core disciplines is necessary.

It can be concluded that the Production & Distribution phase is in the true sense of the word not a development activity. According to the goals set in this thesis only development activities are considered. However due to the fact that the product and production facility are developed further in the production & distribution phase, this phase will be further considered as a development phase in the CDM model.

Finally, the relevant process phases for modelling the CDM model are:

- Product Initialisation
- Concept Development
- Detailed Development
- Realisation
- Production and Distribution

Additionally, it can be assumed for the CDM model that all core disciplines have the same process phases.

4.1.1.3 Gateways and Documentation

Each product passes through similar process phases during its lifetime. Each of these phases is connected to several goals, which are checked at the end of the phase. Literature calls these events gateways. To pass a gateway a product must have its maturity evaluated to be as good as required [Amstrong, 2001]. Once passed the gateway the product enters a new project phase. If it does not pass the gateway the product is reworked or the project is completely terminated. The evaluation process of the gateway is a go/no-go decision process. This approach organising a development process through gateways ensures that a constant level of quality of the project can be kept throughout the complete product's life. The term gateway should not be confused with the term milestone. A milestone just describes an event, which should be reached in a certain period of time. An evaluation does not take place.

One of the goals of this work is to establish a decision-based model. Therefore the author derived these gateways before the processes and their process elements were determined. The gateways used in the model have to be passed for all core disciplines. However, the core disciplines must adapt the single decision of each gateway to their individual product. The gateways listed below are the main gateways for level one and two. At a more detailed level there are more gateways and decisions, which are more connected to the specific product and therefore differ from project to project.

Each gateway has to be documented so that decisions made are written down and can be understood by each core discipline throughout the complete development process. Therefore the documentation for each main gateway is listed in brackets.

- Market idea evaluation approval (Requirement list)
  The market idea is evaluated as to whether it is mature and promising enough to generate product ideas. The approval releases resources for the product development.
- Product idea feasibility approval (Product Concept Study)
  A number of product ideas are roughly defined and an evaluation is carried out to find the most promising. In the following step the selected ideas are evaluated against product and production concepts in respect to the prior defined requirements. It is possible to support this evaluation by building a first prototype
- Final product launch approval (Product/-ion Evaluation Study)
  On one final product concept to be designed in detail and realized is decided upon.
- Final product design approval (Product specification)
  It is decided on whether the product specification is mature enough to be frozen and industrialised.
- Joint product/production approval (Production Specification)
  The product in combination with the production specification is evaluated as to whether it is mature enough to be frozen. This decision is the last possibility to stop the project without loosing major investments. This approval releases resources for implementation (tooling and equipment).
- Start of Production approval (Final Product/Production specification)
  If the produced output meets the product and production specification, the production is approved for regular production. This gateway is often called Start of Production (SOP). It should be noted, that after this gateway a considerable change in responsibility takes place. The responsibility is passed completely from the development department to the production department. The

development departments are acting now as a support function to the production units.

- End of Production approval

  It is decided whether to stop and disassemble the production. The same is also decided regarding spare part production.

Figure 4.1.1.3-1 combines the gateways and the development phases of the product life cycle. It can be seen now that additionally to one gateway after each development phase there are two more important gateways. The second gateway is carried out during concept development and the fourth during detailed development.

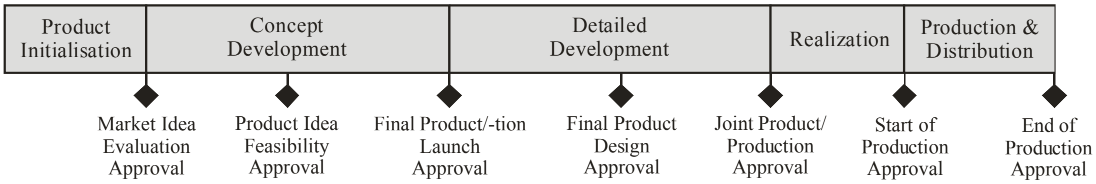


Figure 4.1.1.3-1: Gateways during concurrent development

It should be noted, that a major gateway is not automatically located at the end of a process element. Gateways are implemented at transition points that connect one development step with the following step. Therefore, major gateways can also be encountered during a process element. Further it should be noted that gateways are related to the whole development process and not to a single core discipline. As a further component for the CDPM, documentation improves the development process. It supports the decision-making process, and allows the auditing of existing project data. Moreover, documentation is important for communication between the development team members and is often required by law.

4.1.1.4 Process Elements of the Core Disciplines

According to the SCOR model, decomposing the process results in the process elements. At this stage the process elements in concurrent engineering are connected to a single functional discipline and must be split into the parallel ongoing core disciplines mentioned in chapter 3.2.7.

Despite the individual process elements of the different functional core disciplines, the Kick-off Meeting is the start for every discipline participating in concurrent development.

In this thesis it is assumed that the core discipline Marketing & Sales is involved already from the need recognition phase prior to the product initialisation phase. During the Kick-off-meeting marketing & sales pass their knowledge and collected information on to the other core disciplines. This guarantees that all core disciplines start with the same set of relevant product data.

The process elements of the core discipline product development are described in Pahl [1995], Ulrich [2000], VDI 2221 [1987], French [1985].

Based on that literature the author can describe the following seven main process elements. These can be merged into a common view:

- Kick-off Meeting
- Clarifying the Task
- Product Conceptual Development
- Detailed Product Design
- Product Realization Support
- Production Test Run
- CI-Team Support to responsible production department

The purpose of clarifying the task is to collect all information about the requirements that have to be fulfilled by the product, and also about the existing constraints and their importance [Pahl, 1995]. Information relating to the product must be collected, missing information detected and all written down in a product requirement list [VDI 2221, 1987]. The output of this process element is the formulation of a product requirement list. The following process elements in product development are based on that list. The product conceptual development phase is basically the requirement list of the product converted into broad solutions in the form of schemes [French, 1985]. The number of different solution principles varies during this stage. The number of solution principles will first diverge and finally must converge until one product concept is established. The product concept is the overall solution of the solution principles [Pahl, 1995]. A product concept is an idealized representation of the structure of a system or a subsystem, in which the characteristics of the elements and their relations, which are an essential of the function, are qualitatively determined [Hansen, 1976].

In detailed product design the product concept is developed further into a product specification. This phase includes the arrangement of forms, dimensions and surface properties of all individual parts, production possibilities, costs estimation, assembly drawing, part lists and all other necessary product documentation [Pahl, 1995]. Often changes must be made during this process element to optimize not so much the overall solution but rather subassemblies and components. The crucial activities are optimization of the principle, layout, form, materials, and of the production process. At the end of this process element, the product specification is frozen. After the gateway joint product/production approval, the product development gives support to the realization of the production. Often engineering changes are made and the product development ensures as an expert that the product specification is met. During the production test run the product developer together with the production developer, verifies the product and the production facility against the product/production specification. After the start of production (SOP) the production facility is usually continuously improved. Multifunctional teams are established and the product development represents the product expert in that team. The involvement of the product development ends with the end of production (EOP).

Several authors, such as, Chase [1998], Spur [1994], Eversheim [1982], Ulrich [2000], published production development cycles, but none of these cycles cover the complete product life cycle. Therefore, the process elements of production development are orientated on the planning and design process model from Pahl [1995] in combination with the product life cycle from Usher [1998].

Nine individual process elements could be established, namely:

- Kick-off Meeting
- Clarifying the Task
- Production Concept Development
- Detailed Production Development
- Production Realization
- Ramp-up Production
- Production Test Run
- CI-Team support to responsible production department

As mentioned, clarifying the task is the individual process element that is the start for the production development. Therefore information related to the requirements that have to be fulfilled by the product are collected with special emphasis on production issues. In this process element the focus is on production issues. A production requirement list is defined and aligned with the product requirement list. By that the discrepancy of both requirement lists, which naturally occur, is eliminated. The result is that manufacturability is now considered in the product concept and critical and risky technology determined. During production concept development, production concepts are worked out for the principle product solutions. Thereby the product concept is not frozen. Changes in production development can have strong impact on the requirements of the product concept. The scope and complexity of the production concept can thereby vary from rework of an existing production line up to the design of a completely new production facility [Spur, 1994]. In detailed production development the final product concept is worked out and expanded with the production concept. The outcome is a production specification mature enough to be realized further. The production specification is then finally frozen.

After the production specification is defined investments in the necessary tooling and equipment are made. With a progressing realization of the production specification the production takes an increasingly physical shape. When all necessary tooling and equipment is available the ramp-up production can be started to raise the daily production volume. During the production test run the production development verifies together with the product development, the product and production facility verify the product/production specification. If all requirements are met, approval to distribute the produced output is given. After the start of production (SOP) the production development supports the CI-Team as an expert on the production. Additionally production development assists during the spare part production.

The third core discipline is Marketing & Sales. In Kotler [1999] marketing is defined as a social and managerial process by which individuals and groups obtain what they need and want through creation and exchanging products and values with others. For this CDM model this thesis assumes that before the start of the Kick-off Meeting, the Marketing & Sales discipline has already been deployed in the Need Recognition phase and developed a rough marketing plan to evaluate the chances on the market. In the case where the evaluation is positive, then an invitation to a Kick-off Meeting is sent out to the other core disciplines.

As mentioned before there exists no lifecycle model that allows extraction of the process elements for marketing. To set up process elements for the presented model in this research sources such as Pahl [1995], Roozenburg [1995], Chase [1998], Magrab [1997] and Kotler [1999] were used to determine the following eight process elements:

- Kick-off Meeting
- Idea Screening
- Concept Test
- Marketing Strategy
- Product Economy Analysis
- Final Marketing Plan
- Market Preparation
- Market Introduction

With the start of the Kick-off meeting, the number of core disciplines and also activities in the development project increases. Marketing & Sales present their information on customer needs, customer targets, competitive environment, constrains, planed cost level, time scheduling, etc. Together with all the involved disciplines it is useful to define a requirement list which includes all important information and a short description of the ongoing work, timetable, monitoring, documentation, special information, etc. [VDI 4505, 1995]. Every discipline can now use this documentation and start with their work. Working towards the product idea feasibility approval, the product and production development clarify the task for their own core disciplines, which results in a more detailed requirement list for both. Thereby new ideas are generated and have to be checked. Marketing & Sales screen these ideas according to the usability of the new product on the target market, estimate of market size, product price and costs. The aim is to drop all non- promising ideas as soon as possible and concentrate only on the promising ones.

The promising product ideas are used in the ongoing development activities to develop product concepts and evaluate them. Some of these concepts can be checked according to their consumer acceptance. Marketing & Sales arrange these tests and present the new-product concepts or selected components to a group of target consumers. The consumers have to express their impressions by answering questions. The answers help to indicate the behaviour of target customers to the product and its chances on the market. Based on that, Marketing & Sales develops marketing strategies for the promising concepts. This strategy defines the way in which the company tries to achieve its marketing objectives with the new product. These objectives are for example intended for the target market, the planned production positioning in the portfolio, the target sales and market share and profit goals for the first five years. After the decision to enter into the Detailed Development phase Marketing & Sales starts a Product Economy Analysis for the chosen product/-ion evaluation. This involves a review of the sales, costs, NPV, and profit projections for the chosen concept. The objective is to find out whether these calculated and estimated results are in accordance with the current term plans. If not, activities must be started to correct the concept to fulfil the objectives. At the end of this process phase the former established marketing strategy and the results of the Product Economy Analysis are used to define the marketing plan. This marketing plan is the base for the Market Preparation in the next phase.

After the product and the production are specified, Marketing & Sales starts with the Market Preparation. The main task is to prepare all issues related to the market rollout, including supplier contact, campaign advertisement, training sales and service personal, organising product support, and organising sales organisation. It is important in this phase that all changes and delays in the production realization plan are coordinated with the final marketing plan. Otherwise it can happen that the product enters the market too early and market preparation is unfinished or the market preparation is completed but no product is available. A bad market introduction can ruin a complete product.

Last but not least the product is introduced into the market. This phase shows the success of the marketing campaign. At the moment of market introduction all distribution channels have to be filled with the products. Since the distribution is developing its own dynamic, it is important, that the distribution network is operating properly in order to saturate the market. Parallel to this Marketing & Sales conducts marketing research management. The market and the customer needs are dynamic and changing their value continuously. Now, a product development process takes a lot of time and new insights according to changes on the market should be implemented as soon as possible into the development process.

4.1.1.5 Quality in Development

Investigating the relationship between quality and the presented concurrent development model raises the question as to whether or not quality should be assured by the previously mentioned core disciplines or if it should be added as an additional core discipline. Quality historically has been assured by a single department, but nowadays the oversight of quality for both product development and production and distribution is referred to as Total Quality Management (TQM). TQM focuses on quality improvement as a driving force in all functional areas and at all levels in a company [Russel, 2003]. Today’s view of quality shows that quality issues and methods are more and more a substantial part of the product and production development process. Quality should be designed into the product and its production process and not simply checked later during fabrication. This adds importance to quality during the development process. From this point of view, assuring quality as its own core discipline would take the responsibility for quality away from the core disciplines. The author concludes that quality assurance cannot be listed as a separate core discipline; instead, it should be a component of all process elements in each core discipline.

4.1.2 Building a Common View

A detailed view of all single components combined in a single view is presented in figure 4.1.2-1. The concurrent development process is presented in a matrix, with the top row showing the development processes. The next three rows show how process elements are assigned according to their core discipline. It can be observed that a core discipline may have to be idle while it waits for results from another core discipline. Rows five and six show the gateways and documentation.

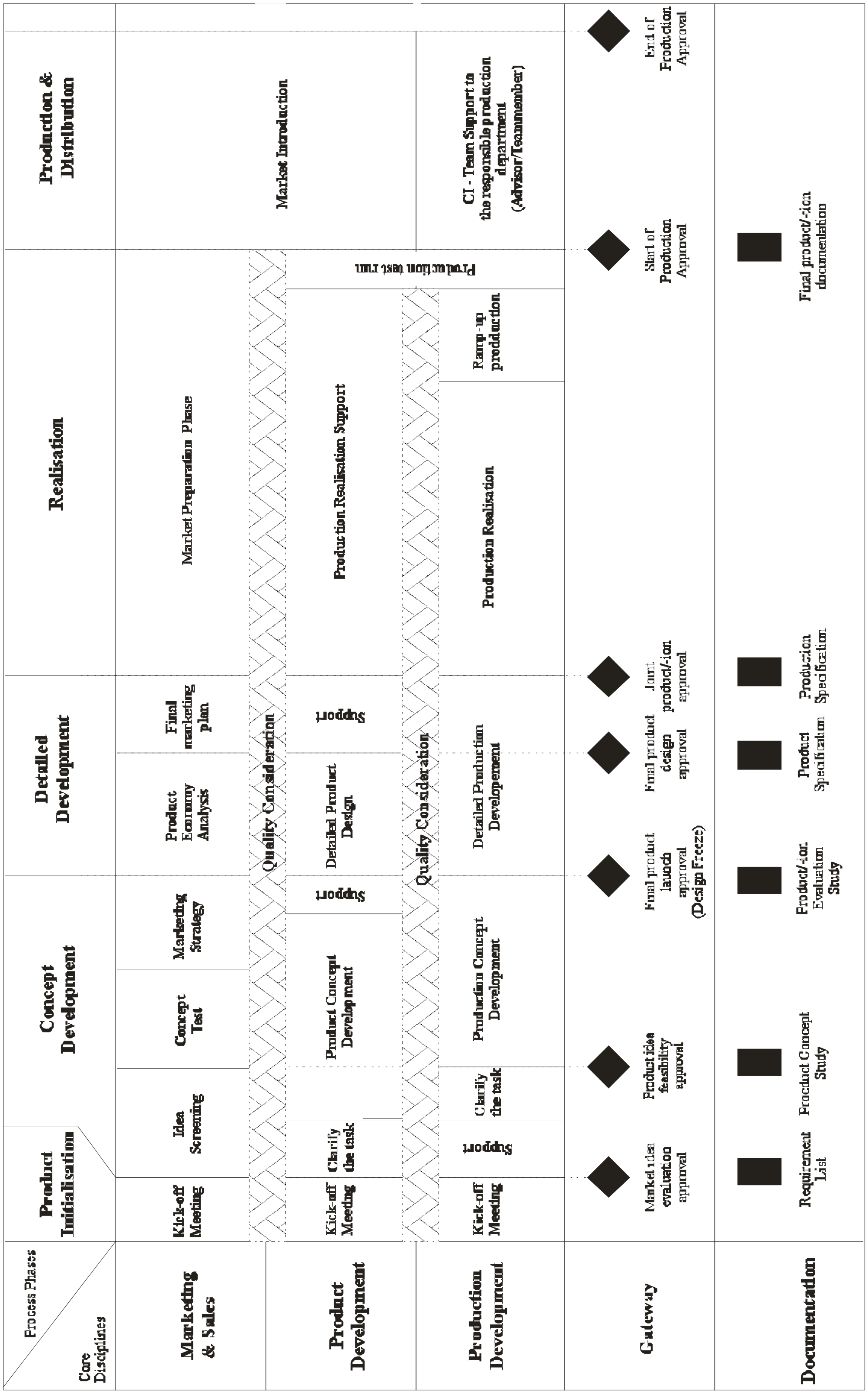


Figure 4.1.2-1: Concurrent Development Process Model for Discrete Manufacturing

Quality is placed between the core disciplines. This illustrates the concept that quality relates to the total concurrent development process and each core discipline is responsible for the aspects of quality that relate to its own field of expertise.

In summary it can be said that this chapter deduced a structuring and chronological organisation of a common concurrent development process for discrete products.

Based on a literature review, see chapter 3.2, six components for such a process model were established. In a next step these components were outlined and then merged into a single concurrent development process model. The result is a process model that all core disciplines involved in the development of a product can use as a basis for a new concurrent development process.

4.2 Project Management for Production Development

This chapter investigates whether project management can enhance production development. In chapter 3.1 and 3.3, both disciplines were outlined and important aspects were highlighted. In this discussion it will be deduced whether production development can be considered as a project, what the contribution of project management to production development is and finally how project management can be applied during production development.

4.2.1 Basic Consideration

First the possibility of handling production development as a project is examined. For this, the seven criteria presented in chapter 3.3.1 are compared with the characteristics of production development:

To 1. “Defined Purpose” Answer: Yes – Production development is carried out according to customer requirements. Thus, there is a single, definable objective.

To 2. “One-of-the-kind” Answer: Yes – Both, production and product are new and thereby the production development is a unique undertaking, even if the production development is constantly repeated with a very low frequency (see figure 3.1-1).

To 3. “Temporary activity” Answer: Yes - SOP (Start of Production) is the final stop of production development, activities after SOP are not the responsibility of production development.

To 4. “Multidisciplinary team” Answer: Yes – The product developer is part of the product design team and for a certain project size an overall manager is assigned. In SMEs only one person is often responsible for production development and involves suppliers and other organisations in his work. In larger companies it is more likely to have a team approach. However, production development always requires a multidisciplinary setup.

To 5. “Uncertainty” Answer: Yes - Production development is repeated at a very low frequency and often new technology or processes are involved.

To 6. “Importance” Answer: Yes/No – Production development can be carried on a small scale, also in larger companies. So it depends on size of the project in relation to the overall revenue of the company that determines whether there is something at stake or the organisation is in jeopardy.

To 7. “Work process” Answer: Yes - Production development is process orientated. It moves through phases, gateways and departments to achieve a fixed goal.

It can be concluded, that production development can be seen as a project, when a certain project size is reached and substantial organisational resources are used (money, people, equipment). Especially in small companies many development projects can be carried out at the same time competing with each others resources. By nature, production development includes unfamiliarity, interrelatedness of the functional areas, changing environment and risk to the reputation of the company. The only criterion, which defines production development as a project, is the magnitude of the effort.

If the project is small and hence the magnitude of the effort too low, production development should not be handled as a project. For example, minor technology or product modifications do not normally require a project management approach and an Engineering Design Cycle is more appropriate. However, this does not mean that project management tools and techniques cannot be used to optimize the Engineering Design Cycle.

The second aspect deals with the benefits of project management for production development. As mentioned above it can be concluded that project management supports production development, when the effort is big enough. In this case production development benefits from the general advantages of project management applications:

- Improves production development structuring and planning
- Improves production development cost estimation
- Improves production development execution
- Improves production development control
- Improves flexible organisation for production development

When production development requires input from different departments, project management is essential to ensure the necessary interaction.

The outlined improvements have a direct positive influence on the production’s development time, cost and quality. It can be concluded that project management supports production development in adapting to the new manufacturing environment.

4.2.2 Production Development Project

The third aspect in this section examines how project management can be applied during production development. In the former section was concluded, that project management supports and upgrades production development in today’s manufacturing setting. This section describes how both disciplines can be merged with project management as a guide for the production development tasks.

The result of the integration is project based production development, see figure 4.2.2-2. Production development is nested into the overall product development project which follows a suggested four staged life cycle, see figure 4.2.2-1. A product development project starts with the project identification. The objective and content of the project is clarified, and the project organisation is defined. This can be carried out independently from the production development team. The project team starts the overall project by supporting the feasibility study by contributing to the assessment of the customer or market requirement.

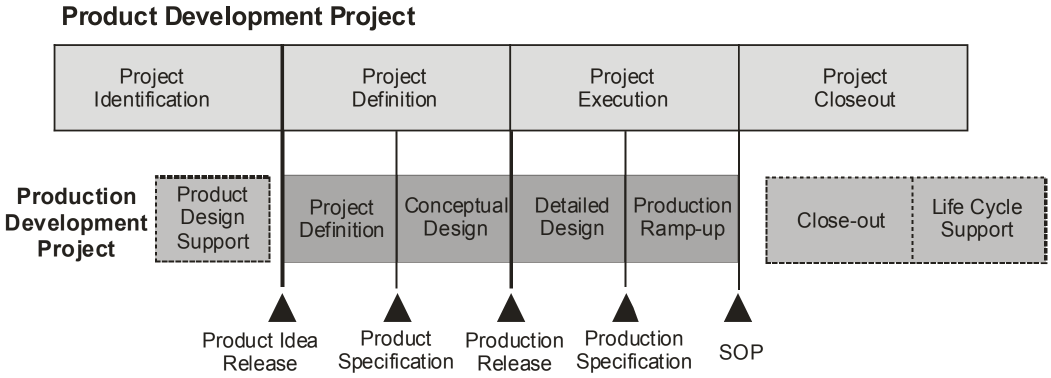


Figure 4.2.2-1: Structure of production development project

This helps to develop scenarios for possible solutions and thereby the resulting functional specification of the product development project includes the necessary production issues.

If the decision is made to proceed with the product, the production development project is started. The production development team then has the clear responsibility of designing a production facility according to the requirements of the functional specification. Like the product development project, the production development project is first defined and the respective work packages are tailored. Responsibilities are clarified as well as the sequence of the distinct work packages and their schedule. Based on this project plan and more detailed product specification, the production developer carries out the conceptual design of the future production facility. The necessary engineering tasks and steps have been described in chapter 3.1 and 3.3.1. The production concept is reported back to product development, where a management decision is taken on the final “go/no go”.

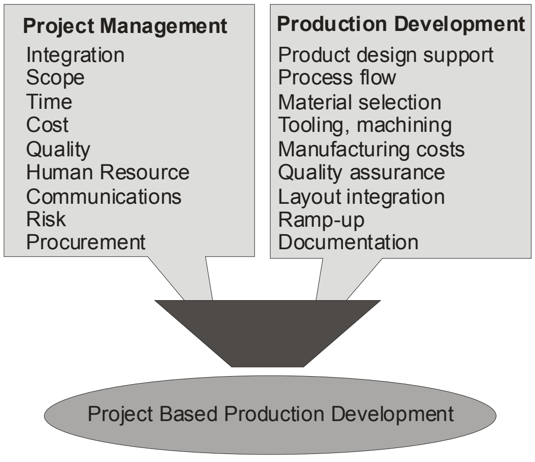


Figure 4.2.2-2: Project based production development

During product development execution, the production development concept undergoes a detailed development and is finally released for production ramp-up. Product development authorizes the planned and scheduled work packages to turn the production into reality.

The results and achievements are measured and reported back and checked against the product development project's scope.

The product development project leader monitors the development time, costs and quality. In the case of variation, proper action must be taken. A ten-step problem solving cycle can be applied to define a recovery plan [Thurner, 1993]. Another task of product development is to manage design changes and to pass them on to production development in the form of standardised Engineering Design Changes (ECR).

After the production is approved for operations the responsibility for the production is transferred to operations. The development team is disbanded when all the work is finished and post-complete reviews are held. For the rest of the product life cycle, the production developer supports operations in continuous improvement initiatives.

It has been shown that the production development project can be described in a sequence of four core cycle phases. In the other three life cycle phases, the production developer participated as a team member in the product development project and in continuous improvement projects.

4.2.3 Production Development Process Groups

The next step is to clarify which core processes are necessary to carry out a production development project. The PMBOK® Guide [PMBOK, 2000] is used as a basis. This guide applies a set of five different process groups, which can be used to describe the structure of production development, see chapter 3.3.1.

In principle the production development process can be divided into two parts: engineering design, which comprises the project definition and the conceptual design, and industrialisation, which includes the detailed design and the production ramp-up. Further it is useful to integrate the project definition into the conceptual design, since project definition and conceptual design form a work unit and the execution time is normally much shorter than the time required for industrialisation. The engineering design now uses all five process groups to achieve the goals of this project phase.

The industrialisation has to be seen in two phases, since from the production developer perspective the detailed design is a continuation of the engineering design, while ramp-up sets the production design into reality. The focus changes during ramp-up towards project execution and monitoring as well as change control. This means that ramp-up does not need another project initiation and that the ramp-up planning is directly connected to the detailed production design planning process. Since detailed design and ramp-up follow the same overall goal, having one common controlling process is recommend. The summarized overview is illustrated in figure 4.2.3-1.

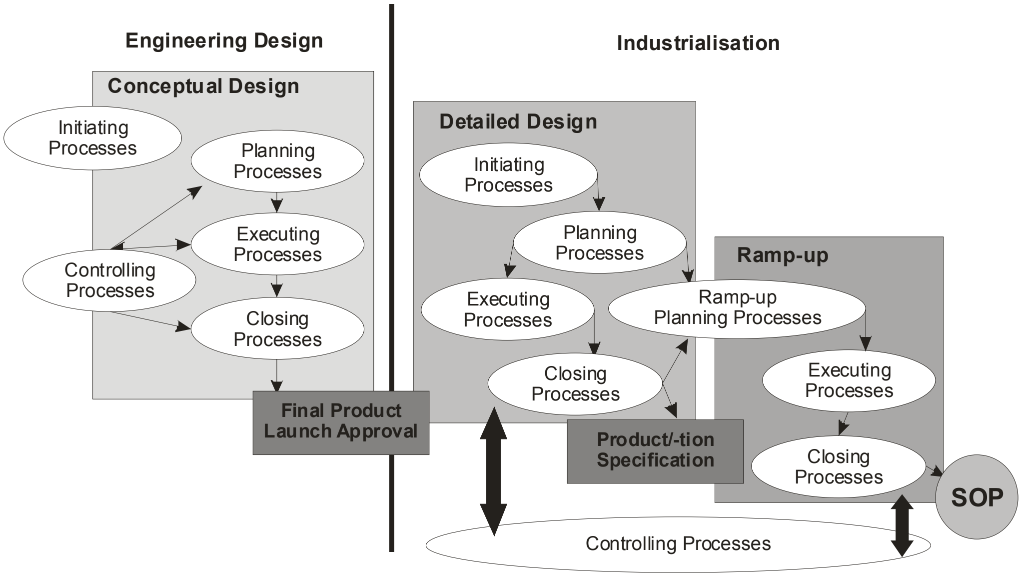


Figure 4.2.3-1: Structure of production development

4.2.4 Production Development Processes

The PMBOK® guide [PMBOK, 2000] describes the interaction of all individual processes within a process group. Each individual process is connected to one of the nine knowledge areas. The PMBOK® guide states that these project management processes are applicable to most projects. In this thesis, these individual processes have been now adjusted to fit production development.

The question arises whether the complete body of knowledge is necessary to conduct production development. Risk management carried out late in the product development process introduces a lot of uncertainty, since critical technology and processes can cause the total project to fail. Thus, the project's risk should be determined early in the product development process and should be established at the start of production development. It can now be concluded, that risk identification and analysis for the project is not relevant during engineering design and industrialisation, except in controlling it.

Usually the production development organisation is fixed in the company's structure and is therefore independent from the ongoing project. The production developer is requested from product development as a specialist, but remains embedded in his own functional department. Thus, organisation planning, staff acquisition and team development takes place in product development or in the company's overall organisation and therefore is especially in SMEs of no direct concern to production development.

The conceptual design, which is the actual start of production development, comprises all five project management processes. With initiation of this a new production development project is formally authorized. Figure 4.2.4-1 illustrates the planning processes.

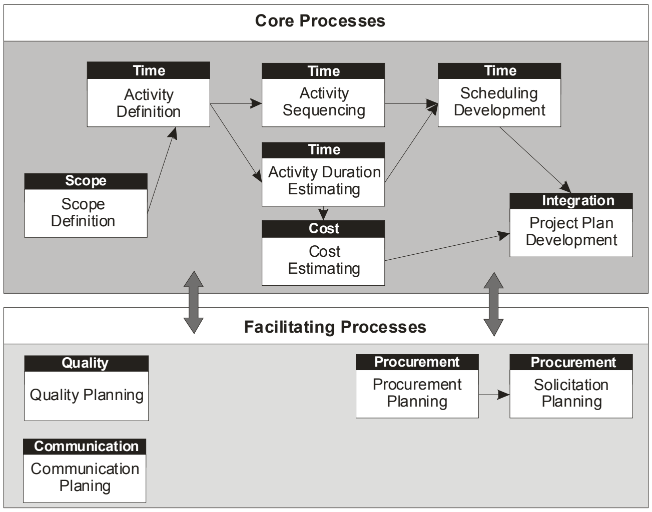


Figure 4.2.4-1: Conceptual Design Planning

At the beginning, the scope and major production development deliverables are defined. This outlines the responsibilities and WBS (Work Breakdown Structure) structure of the design of the future production facility. The performance can often be measured quantitatively in terms of tolerance values and production volumes or a production period. The WBS of production development is either based on experience or standardized working structures. Production development often repeats itself. This allows for the creation of production development templates, which are used to establish a suitable WBS structure. For completely new planning a theoretical approach to production development can be used as described earlier in this thesis.

During the activity definition, the WBS structure is further refined with the specific activities. Again, prepared templates based on the experience from earlier production development projects can be used. Activities are chronologically sequenced with the help of diagramming methods and their durations are estimated. This is the basis for the development cost estimation. The costs are reported back to product management for controlling. Next the master schedule is established and all contributions are combined in a master project plan. The master project plan is then approved and forms the basis for the execution phase. It is supported by quality and communications planning as well as procurement. It is important to set quality and report checks to ensure that goals are met and problems are not passed on through the complete process. At this stage a make/buy analysis and the choice of potential supplier is useful to start the procurement process.

The next step in production development is the conceptual design execution, during which the project plan is executed, see figure 4.2.4-2.

Defined activities, such as process design or transport planning, are carried out and work results produced. Changes are requested should variation from the original goals occur. In this phase, the engineering design including conceptual calculations takes place and hence the predominant process is an engineering design process. This is an iterative process, since the project activity plan can be run through more than once to mature the chosen design solution to the requested level. Quality is assured by audits and checks against the quality standards. Potential suppliers are selected and proposals and bids sent out. Required information is made available to product development in a timely manner.

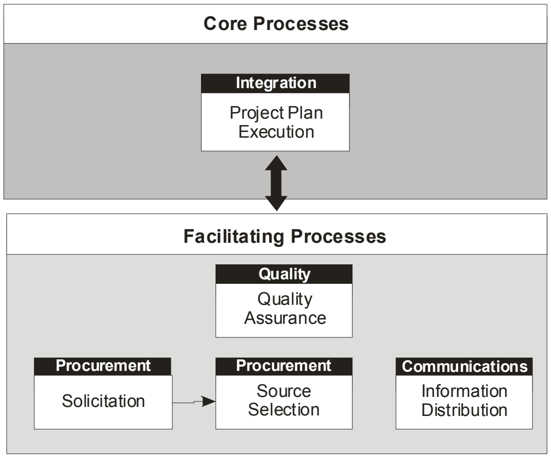


Figure 4.2.4-2: Conceptual Design Execution

Parallel to planning and engineering, the controlling takes place, see figure 4.2.4-3. Scope, its possible change, development time, manufacturing and overhead cost, product and process quality and technology are all closely monitored. Finally this phase is closed and the conceptual design team disbanded.

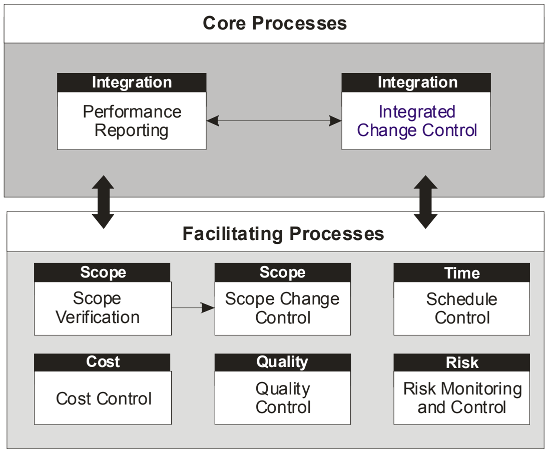


Figure 4.2.4.-3: Conceptual Design Controlling

The next production development step is detailed design. The structure of this step is very similar to conceptual design and detailed design can be understood as conceptual design on a more detailed level with only one production solution. Solutions for all production features are determined and optimized. The WBS structure is extended by error finding and optimization activities. In this phase the long-term procurement is started and contracts are negotiated with suppliers. The detailed design is closed when the production design is mature enough to be finally frozen.

Next, the production can be ramped up, see figure 4.2.4-4. During planning, the set-up and evaluation of a new WBS is the primary activity and again WBS templates can be used from earlier production ramp-ups. The scope for ramp-up was already stated in the previous phases.

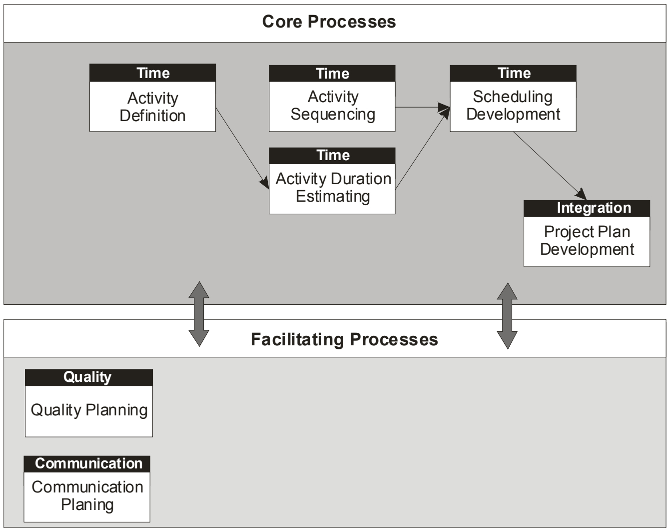


Figure 4.2.4-4: Ramp-up Planning

Its activities are sequenced, their duration estimated and all combined in a schedule, and then written down in a ramp-up project plan. It is again necessary to include quality checks in the form of test runs and audits or process capability analysis. To ensure that all key personnel are informed, suitable reporting systems are established. Based on the ramp-up project plan, the execution can be started, see figure 4.2.4-5. All the production equipment is assembled and personnel are trained. The work results are reported and the necessary information distributed. Finally, the production is verified against the production development goals and the production is approved for operations. The responsibility is passed on to operations and the production development project can be closed, finishing open work and disbanding the industrialization team.

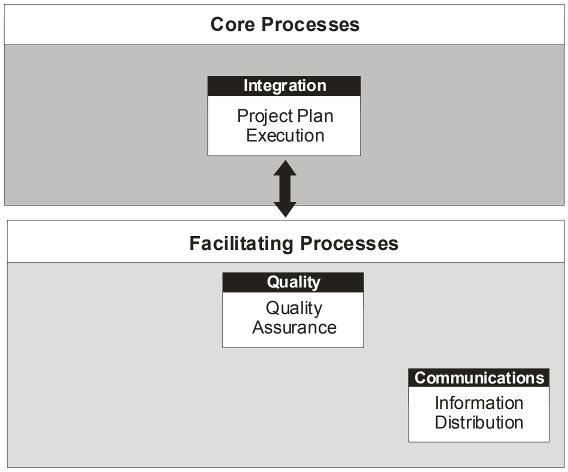


Figure 4.2.4-5: Ramp-up Execution

Both detailed design and ramp-up form the industrialisation, which should be controlled by a single structure. The structure does not differ from the controlling procedure of the conceptual design. The performance is regularly reported and upcoming changes are controlled. This includes the knowledge areas scope, time, costs, quality and risk.

Finally, this chapter has investigated how project management can enhance production development in order to fit into today's manufacturing environment. Three aspects were examined: Firstly, whether production development is a project. Secondly, how production development can generally profit from project management and finally, how project management can be applied to production development.

This thesis has demonstrated in this section that with the help of seven project properties production development can be considered as a project, when the magnitude of effort is big enough. Further it has shown that production development can profit in various ways from project management.

Based on the PMBOK® guide, a project process structure has been specifically adapted to production development. This structure can be used as a general template to guide through production development.

4.3 Multidisciplinary Teams in Production Development

Chapter 3.4 focused on multidisciplinary teams with special emphasis on product development and supplier involvement. It described different team characteristics, such as types, team process, roles and leadership, decision making and problem solving as well as multifunctional teams and supplier involvement in product development teams. This chapter summarizes the findings found in literature and deduces the use of teams in production development.

The first finding is that in literature the use of teams in production development is neither specifically mentioned nor described in detail. It was found, that many authors mention the fact that the team approach is essential to develop and launch new and innovative products efficiently and state additionally, that the concurrent engineering approach is today an essential development philosophy with teams as the basic element. These authors also state that the production developer is a core team member of the overall product development team. This evidence is supported by the fact that some authors, for example [Dym, 2000], [Kušar, 2004], integrate production development into the product development responsibility chart at any developmental stage.

It can now be concluded, that the production developer plays an important role in the product development team and must be integrated as a core team member. It can be further assumed that the production developer uses similar characteristics to all the other team members of the product development team. Surely, this assumption needs to be detailed and checked for the various aspects of product development teams and for the supplier integration in production development. Therefore, the following questions are discussed in greater detail:

- In which specific type of development team is the production developer involved?
- Which team roles are assigned to the production developer?

- What are the responsibilities for the production developer in the team?
- In what way does the production developer influence the decision making process and the problem solving process?
- What are the possible relationships between production developer and supplier in the product development team?

These questions lead to the final aspect of teams in production development and to the leading question:

- What are the consequences for the work of the production developer in being part of the product development team?

4.3.1 Types of Production Development Teams

Traditionally the production developer works in his own department and has primary contact to the other engineering departments, such as tooling or equipment manufacturer. For new product development these engineering functions build a production development team, which is a sub-team of the product development team. Today the responsible production developer is additionally an active member of the product development team; see also figure 4.3.1-1. In SMEs the product development team is often the external customer, while the production development team is situated in their own company.

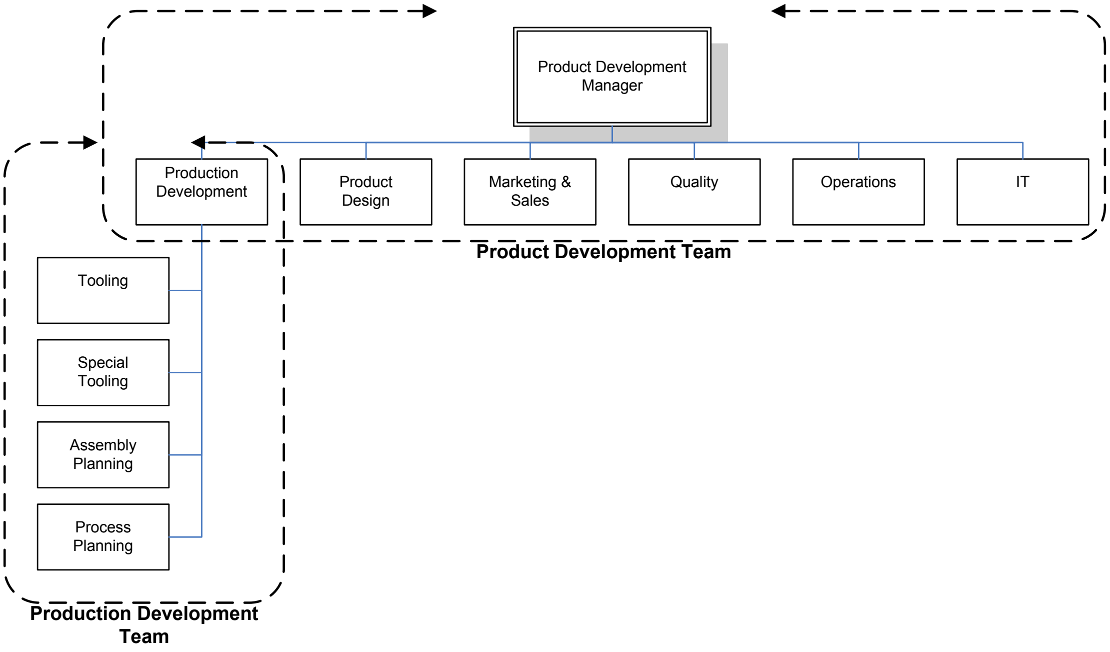


Figure 4.3.1-1: Organisational matrix in product development

It can be seen, that production development builds a bridge between the production development team and product development team. For a sequential development process this is described by Archer [1974], Spur [1994] and Eversheim [1997]. However, this duality of the production developer's role is not described in literature.

Using the description from Aranda [1998] of the different team types it follows that team work in production development is characterized by work teams and task teams. On the one side the product development team forms a temporary task team while the production development team is a functional work team. The production developer now has now two superiors, one in the task team and his functional leader. This duality usually appears in a matrix organisation.

Therefore it could be that the production developer's daily work does not always take place in the same type of team. It depends on the task and on the composition on the team. The production developer spends most of the time in the functional work team. This team can be composed of members of its own department and is independent from the project. The team's task is the participation in product development projects, the optimization of the companies own production development process and the exchange of information and experience. This functional team can be expanded to other engineering functions to carry out the assigned tasks. However, these teams are characterized by regular contact with or without project task assignment. The focus of these teams lies in specific solutions for the production line and the facility. The advantage is the ability of the use of specific experience of each team member to achieve a quick solution on any detailed level. The disadvantage is that the strong focus will neglect outside issues and requirements. It can be concluded, that this teams characteristics leads to a pseudo-group or the traditional group for the functional team, whereas an extended functional work team with an assignment from the product development team can and should be enhanced to a cooperative group.

The other team, the production developer is participating in the product development team. This team forms the characteristic task team. The product development team is temporary, even in SMEs, where the same member can be assigned to the next development project. The diversity of this multifunctional team is much higher than in the work teams. A good example of such diversity can be found in Kušar [2004]. The task of the production developer is to integrate manufacturing issues as early as possible into the product and to ensure an efficient production. Consequently the production developer needs to develop a deeper understanding of the other functions and values as well as promoting the own interests. Further he needs to understand the team process and to understand the other functions behaviour. Especially for SMEs this represents the customer-supplier relationship. This cooperation can occur in different organisational forms as described in chapter 3.5.3, whereas the Direct-Designer Contact and Disconnected-Sub-Project Coordination are most likely to occur. However, in order to achieve innovative results this team must exceed the traditional group and must form a high performance cooperative group. Therefore special team skills are necessary and the production developer as well as all team members must be trained to apply these skills successfully.

4.3.2 Team Roles and Responsibility of a Production Developer in a Product Development Team

The team's roles and responsibilities can be concluded from the types of team the production developer is participating in. One type is the work team and the other type is the task team. The work team can be with or without the connection to the product development team. The leadership can come from the outside or from the inside of the team, depending on the type of manufacturer and type of task.

Considering now the functional work team as described above, the production developer can take all three roles: the facilitator, the team leader or team member. This is based on the fact, that the production developer plays a leading role in this team, either in steering the team or in contributing to the task as an expert. To do that, he must understand and be educated in all three roles. In the product development task team the production developer is most likely a team member. The reason for that is that this team has for larger projects a separate project manager and for small projects the product developer is often the team facilitator and leader. However, this does not mean, that the production developer can also be assigned to the other roles. The responsibilities are assigned project specific with a responsibility chart.

It can be concluded, that the team roles and responsibilities of the production developer in the product development team are the same as for any other person in the development team. The production developer demands no specific or fixed role, except that he must be present and contribute to the common goal. The production development team needs no specifics, only appropriate leadership and empowerment. The roles and responsibility of the production developer in the production development team are not different from those in the product development team.

4.3.3 Decision Making and Problem Solving in Production Development

Decision making and problem solving is a basic and crucial task of the team. In chapter 3.4.5 four different categories of decision are illustrated. The production development process consists of a number of phases from the first concept of a new production facility until the production is disassembled. As further the development process progresses as further detailed the production facility takes more detailed physical shape. And later in regular operations the production is maintained and improved. It is widely accepted, that decisions made earlier in the development process have a larger impact on the design than decisions made later in the process. This can also be applied to production development. It is now apparent, that production development decisions have a major impact on the production facility at the beginning of the development and minor impact on the facility and its people at the end on the development and during operations. The second type of major decisions, such as mergers and restructuring, with a major impact on people, does not belongs to the decisions naturally carried out by production development in SME's.

At the beginning of the production development process decisions are made for example about capacity planning or equipment planning. This type of decision has a major, medium and long-term impact on the later production facility and is characterized by accuracy and quality. A mistake made in this development phase can often be solved only at high costs. The decision process itself is similar to the production development process. After clarifying the task, solutions are worked out and their impact determined. Based on these facts a decision about the best option is made and followed-up during implementation. Later in the detailed development process decisions are made on the sub-system and component level. Additional to the decisions made with a focus on engineering, are decisions made with the focus on people. Examples are the layout of the workplace, decision on shifts, payment systems or continuous improvement workshops. Decisions on tasks should be of acceptable quality and the process is carried out quickly reviewing the situation and deciding on one choice. The decision on people on the other hand ought to be consistent and it is important, that the human resource policy and especially the impact on the employees is considered.

In literature no evidence was found of a relationship between who in the team makes the decisions at a particular development stage or their level of impact. Nevertheless it can be said, that historically, in the sequential product development processes, decisions were made by experts or by an authority with or without a discussion. Today the concurrent approach emphasises the team approach and the team decision. However, the decision process depends on the given task and on the enterprises strategy. So the people involved in the decision can range from an authority without discussion to a consensus decision.

Another aspect described is problem solving. No evidence was found that a special problem solving method for production development exists. This thesis presented the PDCA –Cycle which can be applied at all problems due to its general and well proven nature. It should be noted, that this cycle can be applied both by a single person and by a team.

In summary, it can be concluded that the impact and focus of decisions in production development depend on the production development process. As the further the process progresses the less impact decisions have on the project. Decisions with minor impact are also made with the focus on people. Apparently with the progress of the development the decision process changes. No evidence was found that a certain person or group is responsible for the decision. So, the number of persons involved depends on the company's strategy and task. Also no evidence was found that production development uses a special problem solving method. Thus, any general problem solving method can be adjusted and applied during production development.

4.3.4 Supplier Involvement in Production Development

Suppliers play an important role in production development. It was found, that the role of the suppliers in production development can range from a part manufacturer to an active member in the development team. Further, the supplier can be integrated into the development process at any stage. The relationships are different at different stages, such as R&D alliances and outsourcing. Thus, the influence the suppler has on the future production facility ranges from standard part delivery to the whole development responsibility for a production sub-system. It can be concluded, that production development includes a large amount of cooperation with suppliers at different involvement levels. A detailed description of cooperation in production development could not be found in literature.

This thesis uses two aspects to describe the relationship between the supplier and the customer; first the dimension of involvement and second the coordination strategy. The first aspect describes the tasks dimensions, degree and moment of involvement. All three dimensions occur in production development. As mentioned the degree, task and moment of involvement are flexible and depend on the production development situation and the enterprise development strategy. It is possible to pass on different degrees of responsibility at all three mentioned stages of the development process, namely production concept development, detailed production development and production realization.

Moreover, the integration of the supplier needs coordination. Four different kinds of cooperation were presented in this thesis. It is most likely, that bureaucratic control does not appear in production development, since team contacts are not made on the highest organisational level. All other coordination strategies are possible in production development. If the supplier is competent and the task has low interdependency then a disconnected sub-project coordination is possible. Typical applications could be standard machine development or standard part delivery. The direct designer contact and the project integration coordination depend again on the task and the company's strategy. If the task is complex, integrating the supplier into the development process is recommended. But this is difficult if there is more than one supplier for the component or service. A typical application could be the integration of outsourced services, like FEM analysis or prototype building. If the task does not acquire other functions other than production development or does not need higher strategic support then the direct designer contact is recommended.

It can now be said, that the supplier is an active player also in production development. The organisational integration depends on many factors, whereas no specific cooperation was recommended in literature. Moreover, the type of cooperation must be determined for each new situation in the form of how and when to involve the supplier and which task and which cooperation strategy is appropriate. This needs an understanding from the production developer of the supplier's strategic role in the production development process. A guideline or approach is not stated in literature.

4.3.5 Team Work in Production Development

One aspect of this thesis focuses on how multidisciplinary teams influence and contribute to the work of production development. In general it can be concluded, that multidisciplinary team-work is the primary organisational form for production development. Thereby production development is basically carried out in two different autonomous teams, the product development task team and the production development work team. The production developer's roles and responsibilities can be different in both teams. It can range from being an expert to being a leader in the form of a facilitator or a team leader. It follows, that the production developer must have an understanding of the expectations and values of the other team members. The production developer participates in two kinds of teams, where the presented team process is very similar in both teams only differs in repeating frequency. The production developer must take this into account when working in either team. Further it is apparent, that the team is not composed just of internal functions. External function such as suppliers can be part of the production development and product development team at any stage with different types of cooperation. The production developer therefore must have a concept and strategy for the supplier involvement and this must be communicated to the other team members, for example in form of a responsibility chart. It is also important for the production developer to recognise that both teams can excel to a different level of maturity, in order to know when the team can start producing results. Another aspect is problem solving in teams, which is a new structured working method for production development. Decision making in the team is also a new method of production development, where the production developer can be involved in this decision as a decision maker or as a consultant.

Finally it can be said, that multidisciplinary team-work adds a new facet to the work of production development in form of a new organisational form. Moreover, these days the production developer must take responsibility, make decisions and solve problems. Nevertheless, creativity still plays a very important part in production development. Therefore, the production developer must be further educated in various aspects of team-work and develop the respective team skills. Furthermore, multidisciplinary team-work expands the scope, so that development suppliers are considered in various forms. Finally, multidisciplinary teamwork extends the production development's toolbox and as a result enables production development to develop and implement innovative production lines and facilities.

4.4 Tools and Technology for Production Development

In chapter 3.5 a summary of tools and technologies stated in literature was presented, which can be used directly in production development or can be adopted from adjoining fields, such as project management and multidisciplinary team work. The goal of collecting all available tools and technologies is an unachievable one. Therefore, this thesis has focused on tools and technologies which were most commonly listed in literature. In a first step general observations are described that are mentioned in all the different tools and technologies. In a second step the tools and technologies from production development are analysed. Then the tools and technologies of the adjoining fields are examined for their contribution to production development.

First it can be said, that the basic requirement for each suitable tool and technology is a general contribution to the progress of the production development process. They must be able to transfer a production development input into a production development output. To do so, any tool and technology for production development must fulfil the following requirements:

- Tools and technologies must decrease development time, cost or increase the quality of the production development process or the final production facility, and
- tools and technologies must be applicable in one of the production development phases, or must contribute to one of the production development tasks, and
- tools and technologies must have an origin in one of the categories of the Body of Knowledge for production development.

It can be concluded, that production development, project management and multidisciplinary teams have a direct influence on the effectiveness and efficiency of the production development process. But only the methods of production development can influence directly the future production facility. Thus, tools and technologies can be found in the following categories, see also figure 4.4-1:

- Tools
    - Production Development
- Technology
    - Production Development
    - Project Management
    - Multidisciplinary Teams

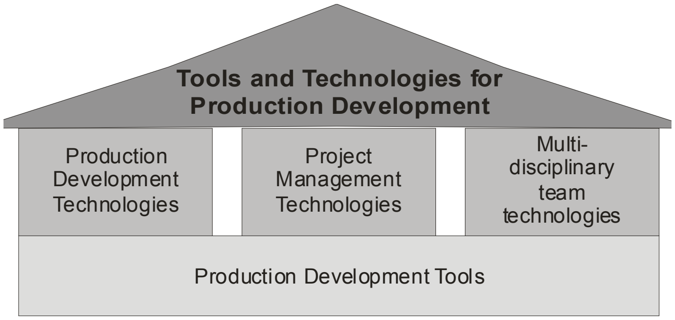


Figure 4.4-1: Production development working methods

It was found, that there are numerous available tools and technologies that can be used for different production development task at the different development stages. The tools and technologies listed below seem to have a generic nature, and can be used at any time in the development process:

- Guidelines
- Experts judgement
- Templates
- Checklists
- Databases
- Standards and procedures

Another generic technology that can be found across the mentioned engineering fields is computer support. Computer support assumes the existence of a tool or a technology or a combination of these. The computer is then able to support the production developer in applying these tools and technologies often making them more effective and efficient.

Another aspect found was that tools and technology can serve as an “umbrella” for a set of tools and technologies. For example project management uses multifunctional teams as a technology which again uses brainstorming as a creativity tool. Another example is the make/buy analysis which uses a variety of other tools and technologies again such as brainstorming, mathematical analysis or standards. The reason for this “tool in tools” phenomenon is because of the characteristics of tools and technologies to be applied at different system levels. It follows that tools and technologies for production development can be categorised according to their ability to be used for different system levels.

For production development it is appropriate to use a four system level, namely:

- Factory level
- Production line or cell level
- Machine or operator level
- Machine component level

As described before in chapter 4.2, the project management Body of Knowledge Guide [PMBOK, 2000] applied on production development results in a reduction of the necessary project management phases. Moreover some phases will be repeated, for example project plan development will be carried out in conceptual design planning and in ramp-up planning, see chapter 4.2.3 and 4.2.4. Thus, some tools and technologies can be used twice at different stages in the development cycle.

After analyse of the tools and technologies applied directly to production development, it can be concluded that for each mentioned task in the production development process there exists at least one working method. Often literature states more than one tool or technology for a single task and the question arises about the general differences between these tools and technologies. It was found, that the same tools and technologies can be applied at different system levels and at different problem situations. For example checklists are applied in many different situations in the production development process. Also experts can be used for almost any kind of problem situation. Thus, some tools and technologies are more flexible and can be adapted to the different tasks in the production development process. Moreover, it was found that all mentioned methods are independent tools and technologies and thus, are not automatically connected to a specific task or industrial sector.

Another characteristic of production development is that the tasks are often complex. Now, most mentioned tools and technology highlight only a single aspect of the problem, neglecting the surrounding project environment. Therefore another tool or technology has to be used to carry out the other aspects of the project. A technology combining all the tools into a production development project was not found. However, some exceptions do exists. One is the Quality Function Development (QFD) method. This method can be theoretically applied to the complete product development process and thus, also to the production development process. But, regular application in larger projects could not be found; only applications for special tasks, for example for machine tool development, see Zoschke [1997].

Furthermore, all tools and technologies can be categorized into two groups: (1) *Determination tools and technologies and* (2) *Optimisation tools and technologies*. The first group describes all tools and technologies that are applied to get a quantitative result and the latter group to get a qualitative result. However, both groups can be used in the same task; see for instance the DFA guidelines and the DFA house of assembly.

The use of project management technologies adds the dimension to production development enables the determination and control of time, cost and quality of the development process itself. In the recent years, the three factors became very important in gaining a competitive development process. Moreover, project management technologies connect all production development tasks into one single manageable process. It is now possible to synchronise and adjust all production development tasks' output to the subsequent tasks' input. As mentioned before the relevant project management technologies can only influence directly the development process and not the physical properties of the production facility. It follows, that these technologies are optimisation technologies, which enable the production developer to do their jobs, the project constraints of time, cost and quality. Since these technologies are not in the production developer's standard toolbox, they must be added on and the production developer trained.

Project management provides several technologies to achieve the production development cycle time. All mentioned technologies are applicable and their use depends on the importance of meeting the development time of the project. All methods are based on the fact, that it is possible to divide the development process into discrete phases and to estimate the duration of each phase. Cost determination technologies are already mentioned in the production development tools. The latter group describes the manufacturing cost of the product while project management technologies determine the production development cost. The principle of these technologies is quite similar to the "time" technologies. However, it is assumed that the development costs can be broken down into several independent elements. Similar to the development costs technologies are the quality technologies previously mentioned in the production development tools. These technologies are very similar, especially the statistic and graphical technologies, but project management technologies focus on the quality of the development process. Besides, all project management technologies can also be used to control the production development process and by that ensure the progress is checked continuously against the requirements.

Based on the PMBOK [2000] it can be concluded, that there are more aspects driving production development than time, cost and quality. These aspects are integration, scope, human resource, communication, risk and procurement, and technologies that are available to the production developer. Moreover, the respective technologies are not only used in one of the project management categories but are also in placed in one of the production development project stages. Using the production development cycle as stated in chapter 4.3, the production developer is able to use the proper tool directly in the right stage in the development cycle.

Also mentioned in the project management literature is the SWOT analysis. This technology identifies the strength, weaknesses, opportunities and threats to production development. This is the opportunity of the production developer to distinguish between the value adding and value destroying activities. The proper handling of all the upcoming SWOT elements will raise the value of the complete production development process.

All in all can be concluded that project management technologies add a new dimension to production development enabling it to determine and control the production development process itself. Since these technologies do not belong to the standard repertoire, the production development has to put extra effort into learning and applying these technologies.

The technologies of multidisciplinary team work are another important contribution to production development. It is apparent that creativity in teams is essential. Without creativity the production development process cannot exit. Literature provides numerous examples of technologies helping the production developer to solve problems creatively. In general, all the mentioned technologies can also be used in production development. However, only limited evidence was found using the suggested methods in production development. Some widely used technologies are brainstorming, wishful thinking and analogies. The importance and handling of creativity itself is not mentioned in production development literature. The production development process can also be considered as a sequence of problem solving processes. It was found, that problem solving technologies are already used in production development. The PDCA Cycle is often mentioned and used to improve the production facility. Further statistical and graphical methods are used and mentioned in literature related to production development, i.e. PFMEA, or fishbone diagrams. All the literature emphasises the use of teams and that all of the technologies are suitable for development teams, and by that also for production development. Decisions are an integral part of today's production development process. Decisions in production development can vary from one-man-decision to consensus. The decision-making technologies found in literature are either of general nature or already adapted to a development process. In principle, all presented methods are technologies with reliable factors. The nature of these technologies leads to the conclusion, that they can also be applied to production development. However, again no evidence was found, that these technologies are used in production development and it is very likely that they need to be adopted individually. A team in production development needs to be organised and integrated in the overall development process. It was found, that the responsibility chart is a proven technology. In supporting the organisation of the production development team, technologies are available to plan the team, to find suitable team members and to develop all members as team players. But a team is never without conflict. This is also valid for the production development team. To resolve conflict several general technologies are available. Most of the technologies try to resolve the conflict between the involved parties. If this is not possible, the "stakeholder map" isolates the person which originated the conflict and moves the person into a position, where it cannot influence the team any longer. Finally it can be concluded, that the production development team has many technologies available to start and develop the team, to organise it and achieve the desired results.

Having all the tools and technology available, it is then important to apply the right tools or technology at the right time. A generic selection technology is not mentioned in literature. However, to have a selection technology requires the assumption, that there is more than one tool and technology available for production development. It can now be said that two different philosophies for tools and technologies exist for production development. The first is the use of a single generic production development technology. The advantage is to have always the right technology. However, due to the complexity of the production development process this tool must take numerous aspects into account and will become very complex and large. In the authors opinion is very unlikely that such a tool will exist. It is more likely, that a set of tools, a sort of toolbox can be developed. This supports the second philosophy of having a variety of tools and technologies for each single production development task available and a selection tool which enables the production developer to apply the right tool for the right task. The advantage is that this toolbox is very flexible and an evolution in production development can easily be integrated. The disadvantage is that the selection tool is complex and needs constant updating. Also the selection tool has a strong influence on the quality of the production process.

Finally, the analysis of tools and technologies for production development are summarized as:

- Not all tools and technologies can be used in production development. A production developer can use a tool and technology if it fulfils the earlier stated requirement.
- For every task in production development, as stated in chapter 3.1 and 3.3, there exists at least one tool or technology
- Only the scientific field of production development itself can provide tools for the ongoing task. Only the screened adjoining fields of project management and multidisciplinary team work can provide technologies.
- Some tools and technologies have a generic nature and can be applied widely in the production development process.
- Tools and technologies for production development can be categorised according to:
  - Tool or technology
  - Level of appliance
  - Appliance in production development task
  - Appliance in production development stage
  - Optimisation or determination tools or technologies
- Project management technologies help to manage and control the production development process itself.
- Tools and Technologies for multidisciplinary team work support and manage the cross functional setting of production development.
- There exits no generic selection technology covering the whole production development process to apply the right tool or technology at the right time.

5 A Body of Knowledge for Production Development

In chapter 3 production development and its adjoining fields were presented as stated in the literature. In chapter 4 these adjoining fields were analysed and the author isolated their contribution to production development. The goal of this thesis is now to create a SME compatible generic production development process in a concurrent development environment. The overall approach used in this thesis is to determine a Body of Knowledge for production development and merge it single categories into a generic view. To do so, first a conceptual outline of such a Body of Knowledge is generated and the different categories are deduced from a historical content. Finally the generic view is derived based on literature and analysis described in chapters 3 and 4.

5.1 A Conceptual Outline for a Body of Knowledge

In chapter 3.1 the different kind of development approaches were categorized into three types

- The traditional sequential approach
- The concurrent approach from the perspective of the downstream departments
- The concurrent approach from the perspective of the upstream departments.

In this chapter these approaches will be analyzed to acquire the Body of Knowledge (BOK) for production development.

A literature and internet search revealed the existence of several BOK for different professions; see PMBOK [2000], Armstrong [2001], ACS [1997], APM [2000], SOCE [2000], SWEBOK [2001], DRM [2004], SCPD [2004]. All BOKs found were achieved heuristically and based on experience and "best practice" without explicitly mentioning production development. It follows, that it is possible and most likely that these BOKs are not complete or consistent and must be adapted for production development. Furthermore, production development evolved over years and therefore so did the BOK. However, the BOKs mentioned above are very comprehensive and one can be used as a starting point to acquire the BOK for production development.

Production Development is part of the overall concurrent product development process. Therefore it is reasonable to conclude that the BOK for production development is already included in a BOK for concurrent product development. This of course assumes two facts. First, that the BOK for product development is complete and second that it is consistent. Thus, to achieve a BOK for production development, this research work uses the BOK of the Society of Concurrent Engineering (SOCE) [2000] as the starting point.

The SOCE established the following categories for the BOK for the concurrent development of discrete products:

- Strategy..........How to grow profitability in target markets
- People ....How to get the best out of your most valuable assets
- Process...........How to get the right product to delight your customer
- Tools..............How to develop products in time to costs to specifications at the highest quality and reliability levels
- Technology....How to execute new product development effectively and efficiently

The BOK for production development ought to be included completely or in parts in these five categories, see also figure 5.1-1. Nevertheless, as discussed it cannot be proven that the BOK from SOCE is complete and therefore it is important to analyze whether other categories of the BOK for production development exists.

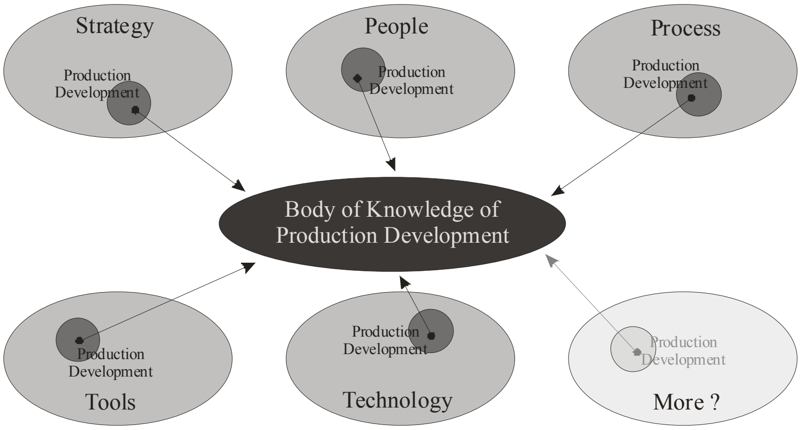


Figure 5.1-1: Approach to the Body of Knowledge for production development

It is apparent, that the BOK for Concurrent Engineering covers a much larger scientific field than mentioned in this thesis. Therefore, it is most likely that the BOK for concurrent engineering includes also knowledge, which is not necessary to perform production development. It follows, that the BOK for production development must be isolated from the BOK for Concurrent Engineering. As a consequence, the achieved BOK addresses the specific needs and requirements for production development as stated in chapter 3.

To find the BOK for production development, the different knowledge categories from the SOCE have to be individually checked as to what specific knowledge is needed to perform production development. Therefore the traditional approaches will be analyzed first and in a second step the more modern concurrent approaches are examined to show the development of the single knowledge categories in a historical content. In the following section, the characteristics of the different approaches are summarized in relation to the categories of the Body of Knowledge for concurrent engineering.

In principle, production development forms a business function and therefore is part of the business strategy. The concurrent approach emphasizes the existence of an enterprise specific product development strategy. The traditional approach concentrates during production development on the creation and optimization of the different subsystems in order to develop the complete production system. The necessary production development decisions are made by the senior management. Decisions from other development functions are almost of no concern. This assumes that the production facility can be development independently from other development functions in the company. The concurrent approach follows the strategy of taking all development functions and all functions of production into account. As a consequence the objective is to optimize the whole production system according to the product requirement, which means that there is a compromise of all subsystem solutions. Furthermore the development process is based on distinct phases. And strategic decisions about the development cycle are made after each phase in form of gateways and reviews. The concurrent strategy includes further early involvement of downstream functions and constantly builds manufacturability into the product in the early design stages. For a summary see figure 5.1-2.

	Traditional production development process	**Concurrent approach from downstream perspective**	**Concurrent approach from upstream perspective**
Strategy	• Based on business strategy • Objective: optimization of costs and outcome • Objective: Concentration on optimisation of subsystems • Decision made only in defined engineering field • Decision made separately by upper management	• Based on product development strategy • Based on system lifecycle • Objective: Optimisation of the whole system (complete value chain) • Overall decisions made after each phase	• Based on product development strategy • Objective: Optimisation to fulfil the product requirements • Manufacturability is one decision criteria to evaluate the “best” design throughout the whole design process

Figure 5.1-2: “Strategy” in production development

It is important, that the production developer has knowledge of the company’s own development strategy. However, the development strategy differs from company to company and is given and established by the upper management. It follows that the production developer is guided by the development strategy and is not directly involved in creating one according to the target market. Therefore the production developer does not need specific knowledge about the creation of the development strategy and needs only the enterprise specific knowledge of its content. As a consequence production development does not need its own BOK category “strategy”.

The next BOK category analysed is “people”, see figure 5.1-3. The activities of the traditional approach are performed individually or in a group of experts from their own field. The organizational structure remains unchanged from task to task. The main organizational form is the hierarchal or functional structure with clear roles and responsibilities for most of the time. Since the organization is mostly fixed and determined by the enterprise, no specific knowledge is needed to perform production development. So, “people” is not a BOK category for traditional production development.

	Traditional production development process	Concurrent approach from downstream perspective	Concurrent approach from upstream perspective
People	• Production development is a distinct department • Production development is the link between designer and production • Promotes intense communication between Designer/Production and Production developer	• Production developer is integrated into project teams • Three core disciplines: Production, Product Development, Marketing & Sales • Early involvement of all core disciplines	• Production developer is integrated into project teams • Three core disciplines: Production, Product Development, Marketing & Sales • Early involvement of all core disciplines

Figure 5.1-3: “People” in production development

To date production philosophies have evolved towards concurrent approaches and therefore also the development of production facilities. The most striking improvement is the multi-disciplinary team approach with early involvement and problem solving [Pawar, 1994]. The development team is working in a parallel manner and production development is part of the core team. It follows, that the production developer influences the development process right from the beginning, and needs therefore knowledge relating to behaviour in a team and to establishing and leading a team. These teamwork skills are necessary in order to carry out production development. Thus, from the BOK category “people” knowledge about multi-disciplinary work teams is needed and form by that an own BOK category for production development.

The Body of Knowledge category “process” describes how to get the right product to the customer, see figure 5.1-4. The traditional approach for production development is fixed, iterative and is repeated the same way for every new production facility. One phase follows the other and the results are presented at the end. The process itself is embedded between the product design and operations. So, a production developer has to know about the sequence of the process steps and therefore knowledge about the production development process is necessary and becomes a BOK category.

	Traditional production development process	Concurrent approach from downstream perspective	Concurrent approach from upstream perspective
Process	• Process based on phases • Production development is sequential and independent from designer and operators • The process is divided into two individual phases: production planning and control • Two different types of development processes: new planning and “re-planning” (modification) • Process is repeated for every new production facility	• Phase/Gateway process • Production development is integrated into the overall concurrent development process • The process is divided into several phases • Production development is viewed as problem • Problem solving within the team • Continuous Improvement is the successor of production development	• Phase/Gateway process • Production development is integrated into the overall concurrent development process • The process is divided into separate phases • Manufacturability is built into the product

Figure 5.1-4: “Process” in production development

With concurrent approaches the perspective of production development widened. For the early involvement of the production developer in the product development process, knowledge of related development fields is necessary. Therefore, it is important to have knowledge about the development process and in particular about the core disciplines Marketing & Sales and Product Design. This generic view of a concurrent development process is called Integrated Product Development (IPD) and is today a BOK category for production development. It should be noted, that IPD is a broader view of the traditional production development process, see also chapter 4.1.

Additionally the understanding of the production development process has changed. The process is no longer prescribed but more the process steps are described and certain activities recommended. To meet the new quality requirement gateways, milestones and reviews were integrated. So, process orientation is today a basic requirement of the development process. Further an understanding for continuous improvement is not only created for the manufacturing process, but also for its development process. Nevertheless, the production development process has become a unique undertaking, and every production development process differs from the one carried out before. To develop a new production facility the development process has to be set up individually from available templates. This new perspective of the development process needs to be managed with the help of project management. In chapter 4.2 this thesis has shown that production development can be seen as a project, when a certain project size is reached and substantial organisational resources are used (money, people, equipment). Furthermore the thesis has shown, that production development can profit in various ways from project management and focuses on time effectiveness and on enhancing product quality. Therefore a new category has to be added to the BOK of production development, namely “Project Management”.

	Traditional production development process	**Concurrent approach from downstream perspective**	**Concurrent approach from upstream perspective**
Tools	• Standard libraries • Production Engineering calculations • Calling on experts for special problems	• Standard libraries • Production Engineering calculation • Decision making tools • Calling on experts for special problems	• Standard libraries • Calling on experts for special problems • Decision making tools • Designer toolbox for ease for manufacturing, such as DFM, DFA, FMEA, QFD

Figure 5.1-5: “Tools” in production development

The concurrent engineering BOK category “Tools” refers to the development of a product according to the requirements, see figure 5.1-5. It should be noted that the actual product for production development is the production line or cells and not the physical product. The literature review, see chapter 3, revealed that most authors emphasize the use of tools. The traditional approaches mention in particular the use of standard libraries and production engineering calculations, such as capacity planning, layout planning. These tools can be found sorted according to their short-, medium- and long-term application.

Nevertheless, production development needs tools in order to develop new production facilities. Therefore “Tools” is also a category for the BOK for production development.

With the concurrent engineering approach the basic tools remained in principle unchanged; they only became more sophisticated and complex. Furthermore, both the upstream and downstream approaches mention a new set of tools in the area of decision making and problem solving. While the tools mentioned by the downstream perspective are orientated on the traditional approach, the upstream view provides the production developer with set of tools especially needed for the early stages of the product development process, i.e. QFD, FMEA, DFM or DFA.

The concurrent engineering category "Technology" comprises the knowledge of the efficiency and effectiveness of the development process, see figure 5.1-6. It is quite noticeable that all development approaches mention the necessity to apply technologies to gain a competitive production development process. Especially mentioned is the use of a computer as a universal support technology to improve the production development process in form of time, cost and quality. The traditional approach uses the computer as design technology to integrate all functions of the enterprise, thus also the production development. The approaches from the downstream perspective expand the use of the computer to improve problem solving, team work and project management. The approaches from the upstream perspective focus again more on the early design stages to support the product designer with production issues as well as the technology necessary for team work and problem solving.

	Traditional production development process	**Concurrent approach from downstream perspective**	**Concurrent approach from upstream perspective**
Technology	• Often computer based: CIM, CAD, CAX, NC-programming	• Technology for problem solving • Often computer based: CIM, CAD, CAX, NC-programming • Technology supporting work team • Technology of project management	• Technology for problem solving • Computerised support technology for DFM, DFA, FMEA and QFD • Technology supporting team work

Figure 5.1-6: "Technology" in production development

However, all approaches emphasize, that substantial knowledge of the technology of the production development is needed to create a production facility. Therefore "Technology" becomes another category for the BOK of production development.

Summarizing can be said, that to perform a traditional production development process the following categories as a Body of Knowledge are needed:

- Production Development Process
- Tools
- Technology

Over the years concurrent approaches became "best practice" in production development and evolved the Body of Knowledge as listed below and summarized in figure 5.1-7:

- Integrated Product Development
- Project Management
- Multidisciplinary Work Teams
- Tools
- Technology

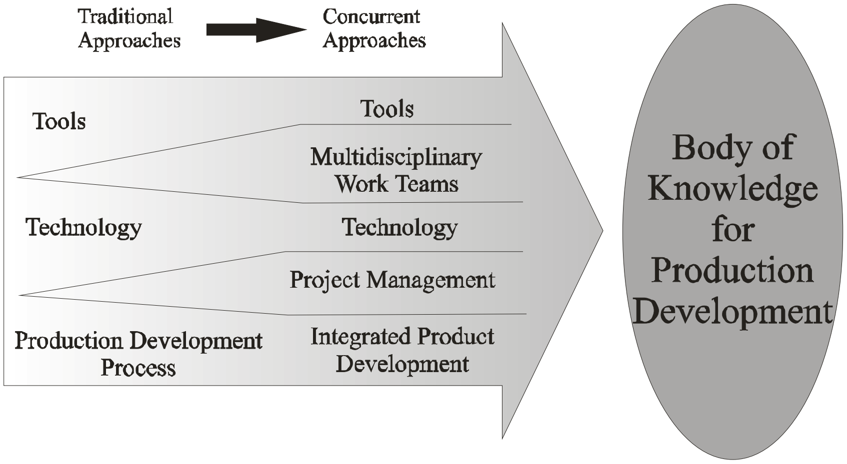


Figure 5.1-7: The development of the BOK of production development

The aim of this chapter was to acquire the Body of Knowledge for production development to help enterprises to better challenge today's changed manufacturing environment. Therefore product development approaches were examined to show their contribution to the development of production lines and cells. Finally these contributions were sorted into categories which together formed the Body of Knowledge for production development.

The literature survey revealed that there are three different perspectives to production development which developed in a historical content, namely the traditional and the down and upstream perspectives. It could be concluded that the BOK for the sequential traditional approaches was formed out of the three categories, Production Development Process, Tools and Technology. The upstream and downstream perspectives are concurrent approaches and to date the BOK has evolved over the years into five categories: Integrated Product Development, Multidisciplinary teams, Project Management, Tools and Technology.

5.2 A New Approach to Production Development

In the last chapter five categories for the BOK for production development could be found and their historical evolution over the recent years illustrated. This evolution of the different categories has an affect on the production development methodologies as stated in chapter 3.1. The traditional methodologies highlight only the category tools & technologies and the production development process itself. The upstream approaches emphasize the use of integrated product development but neglect the production development process, its tools and the use of project management technologies. The downstream approaches again stress the importance of concurrent engineering but miss the integration of project management and multifunctional teams into production development. However, today production development demands it own distinct discipline within the integrated product development process comprising of all five categories.

It follows that production development needs its own methodology which is embedded in the product development process. Such a methodology must be based on the BOK of production development. The five categories compose the elements of a new methodology for production development. In this chapter these five categories will be merged into a new methodology for production development in order to provide SMEs a systematic approach to achieve shorter “Time to market”.

A methodology already including all five categories of the BOK for production development is presented in figure 4.2.1-1.

Additionally, the basic framework for production development is the integrated product development process, as stated in chapter 4.1. All development activities have their origin in this process, so does production development. The integrated product development process is valid for the development of all discrete products and can also be repeated for all future discrete products. The input for the production development process is worked out in the early stages of the product design process. This comprises the scope and basic date, such as yearly production volume, SOP or tolerances. In SMEs however, these important data cannot be provided by other departments, so the production development team must acquire these initial pieces of information themselves, which again can increase the “Time to market”.

As seen in figure 5.2-1 below the development of production lines and facilities can proceed in two possible ways. As found in chapter 4.2 production development becomes a project, when the magnitude of the effort is big enough. Otherwise it can be treated like an engineering design cycle. Thus, a decision prior to the actual production development project launch has to be carried out by the product development team in order to determine the production development effort and its development scope. In the case that the development effort is big enough a production development project is launched as outlined in chapter 4.2. It is important to note, that as a consequence production development is no longer a sequence of predefined tasks, more it is individual adapted series of different activities.

A project cannot perform without an organisation. The production development project now creates its own organisation fitting the projects scope. An example is given in figure 4.3.1-1. This production development team now uses a set of technologies to set up and freeze the structure of the production development process, see also chapter 4.2.2 and figure 4.2.4-2. From this process structure all necessary activities, decisions and documentation can be derived and illustrated with a responsibility matrix as well as communicated with a production development plan to the rest of the organisation, see chapter 4.4 and figure 3.4.6-1. Suppliers will also be integrated at this stage. Similar to the master project plan in chapter 4.2.4, a production development plan is established, which is a planning document stating all necessary activities, their sequence, a schedule and the executing team. Based on this document multifunctional task teams perform the different production development tasks using the proper tools, as stated in chapter 4.4. The successful closing of a task is finally documented in the responsibility matrix and reported to the production development team leader. The team leader controls the progress of the project and if deviation occurs takes corrective action.

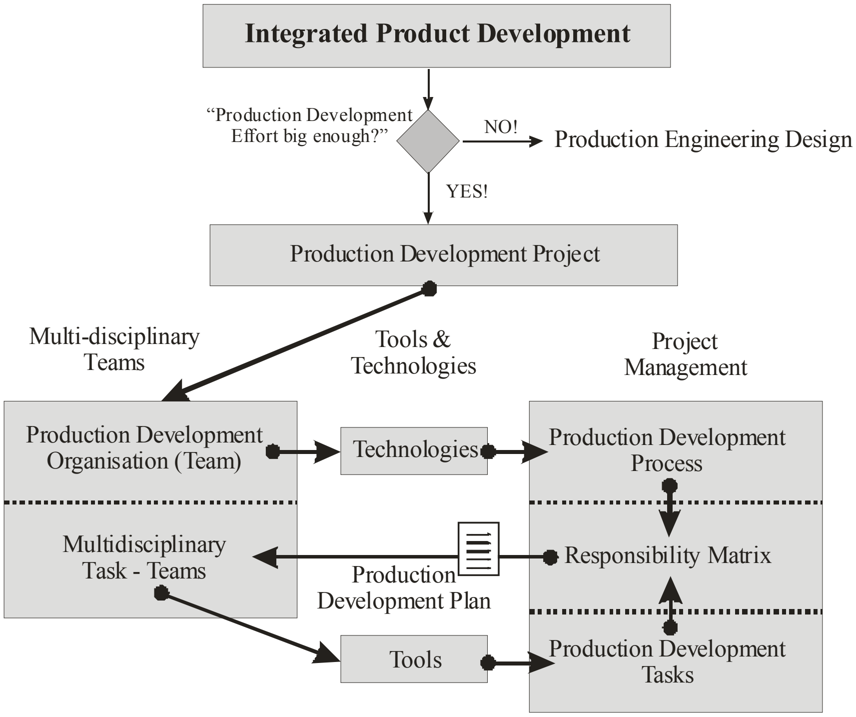


Figure 5.2-1: Production development methodology

In SMEs this methodology can vary slightly depending on the size of the enterprise. In smaller SME's production development is carried out by very small team and sometimes only one person develops the production lines and facilities. It follows that the responsibility matrix becomes a plan of the work sequence since the task-team do not change. Furthermore, it can be that the production development team can be the same as the task teams. In very small enterprises the production development team leader is the same person as the one executing the tasks. Nevertheless especially in these kinds of enterprises the magnitude of effort needed to develop new production lines is always big enough, so it is justified to be handled as a project and requires a production development plan.

Based on this new approach to production development several important interfaces can be identified and further refined, namely:

- The production development project and responsibility matrix interface
- The interface of organisation to tools & technologies
- Supplier interfaces in the production development process

5.2.1 The Production Development Project and Responsibility Matrix Interface

This interface states the process needed to translate development input data into specific activities with the help of a production development project, see chapter 4.2. Every development of a production line or facility is a unique undertaking. Therefore, based on production development project, the author deduced a project management process specially adapted for production development, see figure 5.2.1-2 and chapter 4.2.3. This procedure describes a set of process groups from conceptual design to production ramp-up. Further the production development team needs to look into necessary procurement activities to connect external resources. It is suggested, that this information can be combined best in a responsibility matrix and thereby sorted into a chronological sequence as well as assigned to the internal or external teams and experts. The complete process is illustrated in figure 4.2.2-2.

As discussed in chapter 4.2 each production development project phase can be spit into several processes. Each process again consists of several steps. For example the conceptual design stage has a planning phase. This planning phase consists of several steps, such as scope definition, activity sequencing etc., see also figure 4.2.1-1. It can be seen, that each steps of this methodology includes technologies, which enables the production developer to translate the generic methodologies in specific tasks. The central technology used to guide the production development project is the responsibility matrix, which is able to illustrate which team has to carry out which task at which time and the needed resources. The production development team leader has to observe and control this schedule and the development costs. But it should be noted that a schedule in production development is developed backwards from the SOP date.

So far can be seen, that one important task of the production development team is to transform the generic production development project into concrete tasks and decisions. Therefore the input of the product design and marketing department must be analysed, a scope established and the activities and decisions for this particular production development project determined. This will take an experienced team; see also figure 4.3.1-1, with in-house and external experts. As a basis for the gateway determination the model for the concurrent development process for discrete manufacturing can be used, as stated in figure 4.1.2-1.

The nature of the production development process is that it is repeated at a low frequency. It is therefore possible to create predefined task templates which can be repeatedly used in every new production development project. As a consequence the “time to market” will decrease, due to less planning and problem solving. This is an advantage especially for SME who do not have extensive resources to structure and to search for fast solutions.

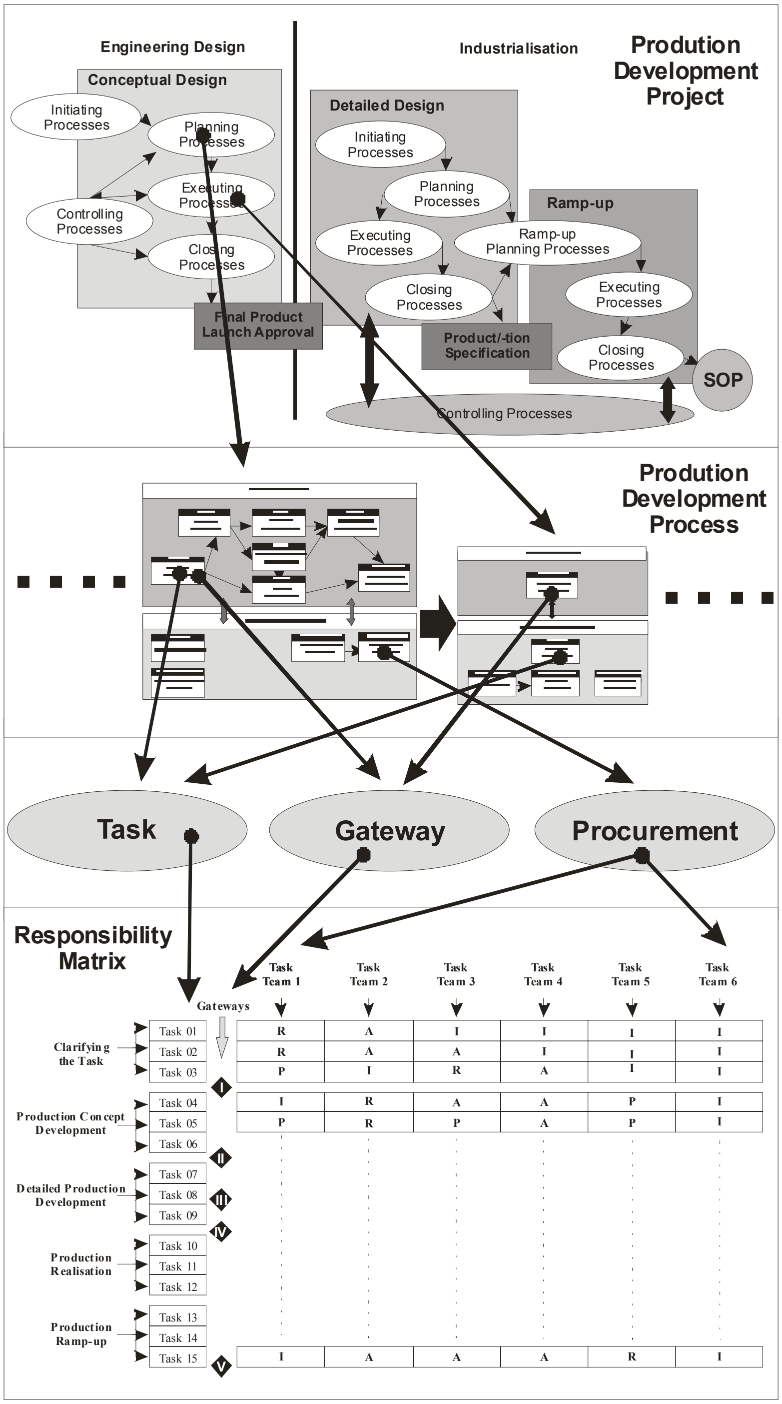


Figure 5.2.1-2: The production development project and responsibility matrix interface

The production development team can also use predetermined task categories as templates to determining the different tasks. As described in chapter 3 and discussed in chapter 4 production development is a distinct discipline in the product development process and comprises of specific tasks to develop new production lines and facilities.

Analysis the literature and the BOK for production development the following tasks categories can be found:

- Product design support incl. material selection
- Process Flow determination incl. Plant rate and time and motion studies
- Tooling, machining, fixtures design
- Manufacturing cost determination
- Quality assurance planning
- Facility and layout design
- Material handling planning
- Ramp-up planning
- Documentation

Special emphasis should be on procurement activities. While establishing the responsibility matrix it will become visible, that not all production development tasks can be performed complete or in parts in-house. It is important to integrate the supplier in the matrix and define the level of integration and cooperation. In the case that there exists no appropriate supplier yet, a process must be started to develop a supplier to a respective level of competence.

Another important task of the production development team is to detect technology which is not developed. Not developed technology is often a major hazard to production development and as a high risk needs special monitoring.

In summary it can be said that the production development team must translate the input data from product design and marketing into tasks, gateways and procurement activities for production development. Thereby the generic production development process is used as a template to achieve these tasks, gateways and procurement activities specific for the actual project systematically. Using the generic production development process ensures that the team covers the complete project. The necessary tasks, gateways and procurement activities are listed in a responsibility matrix and assigned to a task team or expert using the company's own organisational chart. As a further help all tasks have there origin in the different categories stated above and in chapter 3.1. The basic gateways are listed in the concurrent model for discrete manufacturing, see chapter 4.1. Procurement activities lead to supplier involvement in the development process. For involvement dimension and coordination strategy see chapter 4.3.

5.2.2 The Interface of Organization to Tools & Technologies

This interface describes how the organisation of the production development project uses tools and technologies to steer the project, see figure 5.2.2-1. Without the use of the proper tools and technologies no organisation can carry out a project. The use of tools and technologies depend on the task and on the nature of the project. Thus, the production development team and the work team need to select the proper tool and technology prior to carrying out the task. However, since not every tool or technology will fit each task, there are limited possibilities during the selection process. It is necessary that the production development team has access to an engineering toolbox. The selection depends on certain criteria, namely the level of appliance, development phase and task and whether a determination or optimisation tool is needed, see also chapter 4.4. The production development team selects first the technology used in the generic production development process in order to determine the work sequence, costs, schedule and the controlling processes. An overview of existing technologies can be found in chapter 3.5 and its recommend application in chapter 4.4. After the application of the chosen technologies, the responsibility matrix can be established. The production development team also assigns the different human resources to the project which later forms the work teams in the project. These teams can be different kinds of teams. Tasks can be assigned to experts in functional teams or task teams. Also some tasks can be assigned completely or in parts to a supplier. The employment of the team depends on the task. Primarily the functional team should be applied, since it will give the fastest results. Consequently the task can only have aspects of that particular functional area. If more functional areas are involved task teams must be used. This, however, requires a team process as stated in figure 3.4.2-1. Hence, the "Time to market" will increase in comparison to use functional teams or experts, since the team will need a certain time until it can perform.

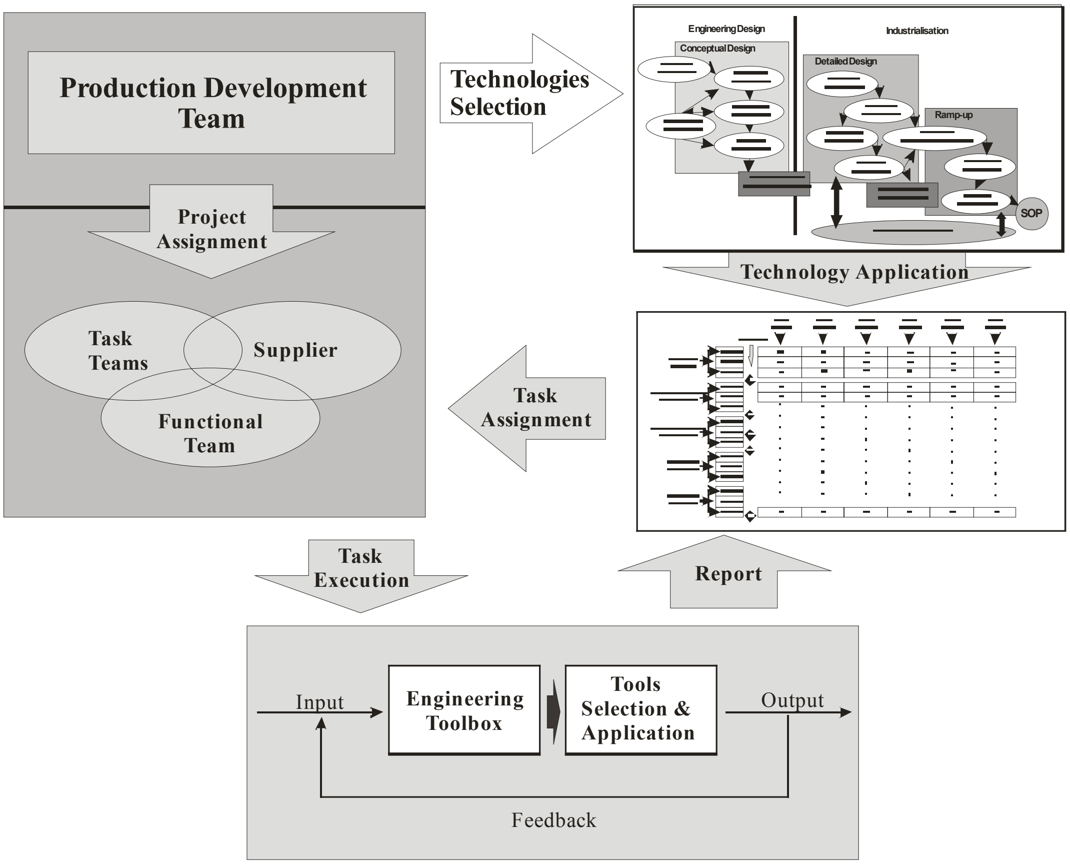


Figure 5.2.2-1: The interface of organisation to tools and technologies

Having the task assigned to a work team the task is almost ready to be executed. As discussed in chapter 4.4, any production development task can be carried out with at least one tool. Hence, again a selection has to take place. The basic selection criteria are the same as for the technologies. Consequently the work teams must have access to an engineering toolbox. After selecting the proper tool, the work team is able to carry out the production development task and report back its successful closure.

In SMEs the organisational flexibility is rather limited. In small SMEs the work teams often consists of the same resources. Additionally SMEs often do not have the necessary resources to establish a comprehensive toolbox. This is also valid for suppliers. Consequently the risk is much higher, that the improper tools and technologies will be used which will lead to delays and thus to longer “Time to Market”. In is therefore necessary either to support the supplier with proper tools or restrict the task to the tools and technologies used.

In summary it can be said, that technologies are selected and applied by the production development team to achieve and assign the necessary production development tasks to the work teams. These work teams again select and apply production development tools to carry out the assigned tasks and report back their successful closure. By this the methodology ensures that the right work is done at the right time, applying a proper tool or technology.

5.2.3 Supplier Interfaces in the Production Development Process

Suppliers play an important part of the production development process. New products are getting more and more complex and a single enterprise is often not able to develop new products alone. In this thesis suppliers are integrated into the development process in order to carry out single tasks independently or together with the company’s work-teams. This thesis does not consider the outsourcing of the complete production development process. However, this does not mean that the cooperation with the supplier is not continued after the SOP, i.e. as part manufacturer.

The presented model for production development provides an interface between suppliers in the production concept and detailed development phase. The production development process, see figure 5.2-1 and figures 4.2.4-1 to 4.2.4-5, includes procurement activities for the integration of possible suppliers. This interface is illustrated in figure 5.2.3-1.

Procurement is a central department for supplier integration. The reason for outsourcing a production development task is either the supplier’s service is cheaper or the suppler offers a service which does not exist in-house. Nevertheless the service must be determined earlier to the responsibility matrix. Together with the other production development departments, the procurement department carries out an analysis, to see if it is necessary to outsource the production development task. As technologies can be used a make/buy decision, expert judgement and contract type selection.

In the case where the production development task can be carried out in-house, the task will be assigned to an in-house work team. In the case where the production development task shall be outsourced it needs further planning. As shown in figure 5.2.3-1, the supplier involvement is specified with the type of external cooperation, see figure 3.5.1-1, and the coordination strategy; see figure 3.5.3-1.

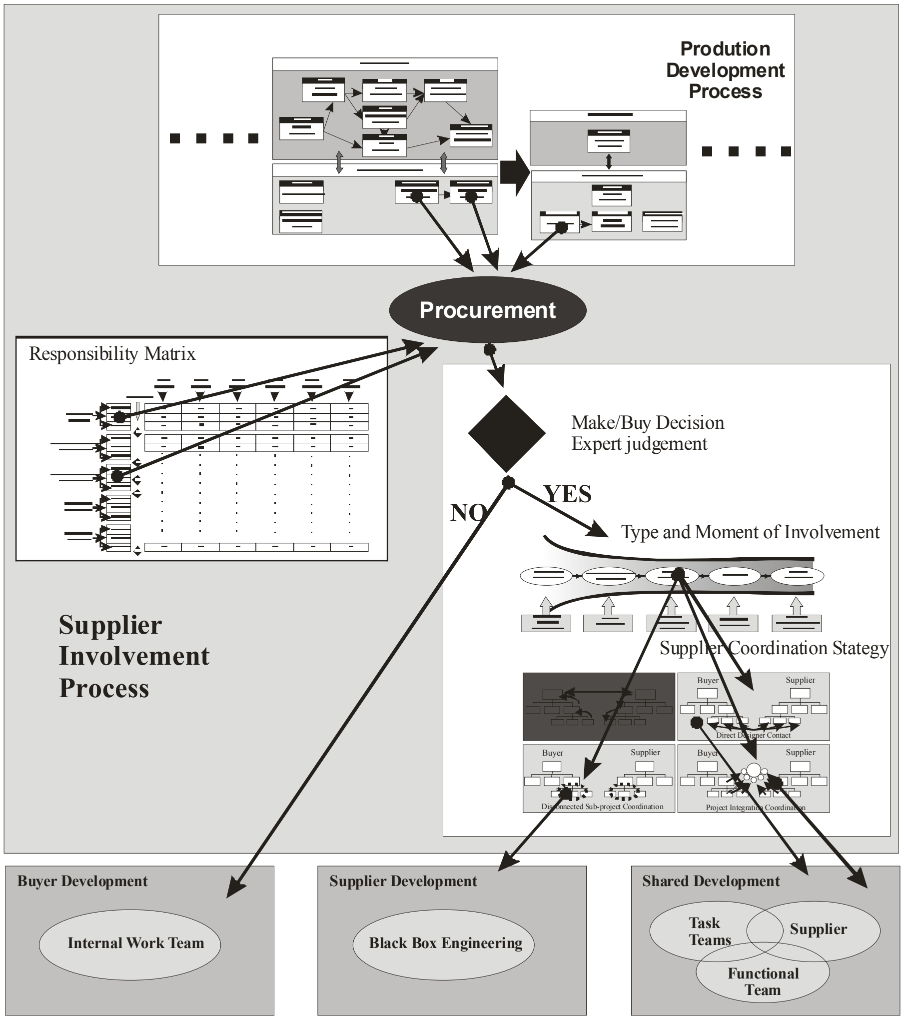


Figure 5.2.3-1: The supplier involvement process

The time of involvement is important since it characterises the type of cooperation, which changes during the production development project from shared R&D alliance to part manufacturers. The coordination strategy is important, since it manages the supplier dependencies and has a strong influence on the team composition. The team composition is again included in the responsibility matrix. As discussed in chapter 4.3, the bureaucratic control is unlikely to occur. If it is decided to start disconnected sub-project coordination then a supplier development is carried out, also called black-box engineering. If the dependency is a direct-designer contact or project integration coordination, a shared development is started. This means, that the supplier becomes part of the responsibility matrix and by that part of the internal production development team. This demands that the customer and supplier organisation have a common set of expectations and contribute together to the overall goal setting.

Finally it can be said, that in relation to outside resources, the presented production development model provides a mechanism to integrate suppliers into the production development process. Thereby the tasks of the responsibility matrix will be analysed for outsourcing. If a production development task is outsourced it depends on the moment of involvement and the coordination strategy as to which type of team is necessary. The teams composition is then integrated into the responsibility matrix.

With the different interfaces defined, the refined methodology for production development is outlined. Figure 5.2.3-2 shows the different stages and interfaces deduced from the combined BOK for production development. Production development is a core discipline in the integrated product development process and therefore an integral part during the early development phases. Thus, production development contributes to all gateways in the integrated product development process; see also figure 4.1.2-1. However, at the beginning of product development an evaluation of the magnitude of the production development has to take place in order to determine whether a production development project has to be carried out or engineering production design. The latter one does not need its own organisation and can be directly controlled from the product development leader.

In the case where a production development project is carried out, an organisation must be established including suppliers and customers. The basic organisational form is the multifunctional team in its various forms. The production development team plans and controls the production development process, while work teams are assigned to different tasks and execute them. These tasks are derived from the generic production development process, which is based on “best practice” and can be applied for every production development. Several technologies support the process of breaking down the different production development steps into concrete tasks and gateways. All tasks are stated in a responsibility matrix and teams assigned to these tasks. Thereby a task can be evaluated for outsourcing and eventually a supplier integrated into the responsibility matrix. Finally the different work teams can carry out the production development task in the determined sequence. The selection and application of the proper tool is crucial for the successful finishing of the task. The finishing of the task is reported back to the responsibility matrix and controlled by the production development team.

The production development methodology is a development process. Every development process is iterative, so is this presented methodology. The production development team controls the results of the different tasks and the integrated product development process controls the progress of the overall production development process. Thus, any deviation can be discovered and production development tasks or phases repeated for optimisation. This implies that the responsibility matrix is a “living” document which will change over time. It is also possible to setup a responsibility matrix for a part of the production development process and complete it later when sufficient information is available. This requires a design change management system to systematically initialise and track design changes and integrate them into the production development process

The presented production development methodology is also a creative process, which is the fundamental basis for every design process. Creativity comes, with the work team and tools, into the development process. Each team can choose and apply the proper creativity tool respectively to the task.

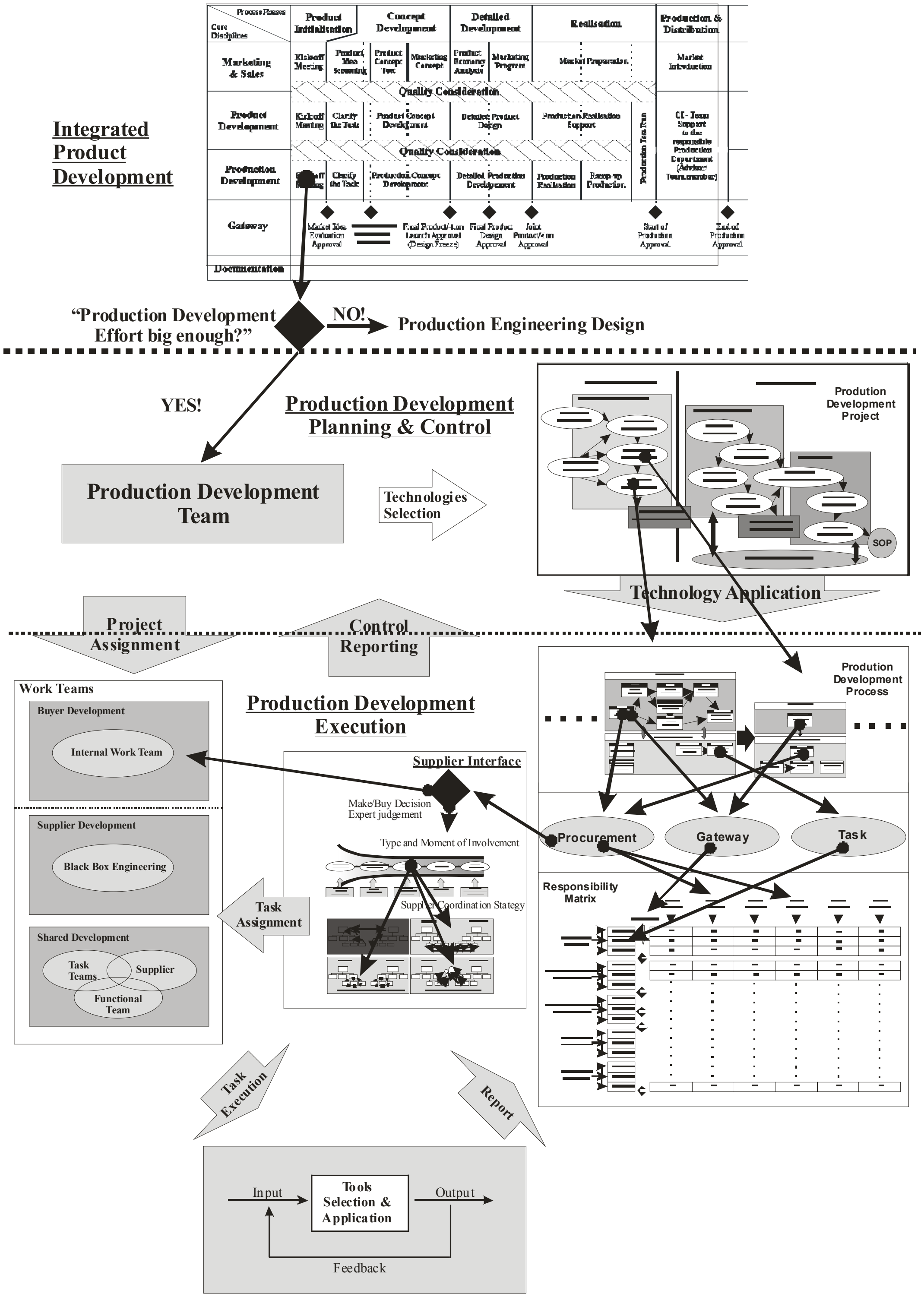


Figure 5.2.3-2: Production Development Methodology

This thesis focuses on SME. This methodology is suitable for SMEs, because it is easy to use and easy to implement, since all elements of this methodology are built up as templates. The systematic approach is flexible will reduce the project delay in SMEs, since it will focus strongly on an efficient production development process. Included controls points will monitor the process and corrective action will be taken when the deviation will occur and not at the end of the production process. This is effectives, because this methodology is based on the BOK of production development and therefore includes all components necessary to develop new production lines and facilities.

6 Conclusion

The evolution of the manufacturing environment in the recent years has had a lasting effect on the production development process in the fact that it is necessary to shorten the time to realize new products and raise the quality of the production development process.

Facing this challenge, the aim of this thesis was to enable small and medium sized enterprises to develop production lines and facilities more systematically and to generically shorten their “Time to Market” and thereby to increase their profit margins. The approach used was to acquire a generic Body of Knowledge for Production Development from “Best Practice” in a historical content and establish a generic methodology for production development, which can be used in small and medium sized enterprises.

Based on the Body of Knowledge for product development and a literature research, five categories for the Body of Knowledge for production development could be determined, namely integrated product development, project management, multidisciplinary team work and tools and technologies. All these categories can be applied to many other scientific fields other than production development. Thus, it was necessary to screen these adjoining fields for their particular contribution to production development. Finally all contributions could be merged into one overall production development methodology. This methodology described the process for a systematic approach to production development which is based on the fact that it includes the complete Body of Knowledge for production development. To adjust this methodology for the various production development projects in industry a production development process template was integrated which enables small and medium enterprises to adjust the development process to their individual needs.

The determination of a generic methodology for production development based on its Body of Knowledge now enables small and medium sized enterprises to approach production development generically and by that handle the development of production facilities more time and quality effective for ever more complex products.

However, it should be noted, that the BOK for production development behaves dynamically, changes over the time, never stands still and is constantly added to while production development is evolving. Consequently, this thesis only presents today’s picture of the Body of Knowledge for production development.

7 Future Research

A number of topics to a generic approach to production development have been described in this thesis, and they can be elaborated further. The different recommendations are summarised in the list below.

- The teams in production development have to apply tools & technologies in order to carry out a task. Applying the wrong tool or technology can result in wrong results or much longer time necessary to carry out the task. Therefore prior to the task there must be a selection process for the right tool or technology. Unfortunately an approach other than using personal experience for selecting tools or technologies in production development does not exit, and further research has the potential to have a positive effect on "Time to Market".
- The integrated product development model presented in this thesis describes the chronological sequence of the different core disciplines involved. The model does not describe the interfaces between the core disciplines and development phases. Effective communication and efficient interfaces between the phases is essential for the success of development. It could be of interest to expand the presented methodology and to integrate the interfaces of production development into the different core disciplines. As already mentioned in the concurrent development literature, such a research can raise the quality of information particular to production development and thereby decrease the "Time to Market".
- The generic production development presented in this thesis is derived from "Best Practice" in project management and literature models of production development. An empirical study of the different production development processes in industry would enable the research to get a refined picture of the production development process by basing the literature models on a "best practice" for production development.
- Multifunctional teams are an important part in production development. In this thesis it was found that production development teams are rarely mentioned in literature. Empirical studies would contribute to the understanding of production development teams. In particular, how creativity as a basic element of development is integrated into the work of production development teams could be of interest.

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