Doctoral Theses at NTNU, 2008:175

Cecilia Haskins

Systems engineering analyzed, synthesized, and applied to sustainable industrial park development

Doctoral Thesis

NTNU
Norwegian University of
Science and Technology
Thesis for the degree of
philosophiae doctor
Faculty of Social Sciences and Technology Management
Department of Industrial Economics and Technology
Management

NTNU
Norwegian University of
Science and Technology

ISBN 978-82-471-1028-7 (printed ver.)
ISBN 978-82-471-1029-4 (electronic ver.)
ISSN 1503-8181

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ISBN 978-82-471-1028-7 Printed 2008-05-16

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When all the trees have been cut down;
when all the animals have been hunted;
when all the waters are polluted;
when all the air is unsafe to breathe;
only then will man discover he cannot eat money.

Cree Prophecy

Abstract

The objective of this thesis is to contribute to the knowledge base of systems engineering and sustainable development to generate insights about applying the principles of the former to the implementation of the latter. The research was conducted under the guidance of Professor Annik Magerholm Fet and contributes to the strategic research agenda of the NTNU Globalization Program.

A recurring theme of the contributions in this thesis has been conceptual simplification – a search for ways to visualize important knowledge such that the uninitiated can understand and use it. The new systems engineering views are intended to put the advantages of systems engineering within the grasp of non-systems engineers. In the same way, the concepts of sustainable development are seen to have the ability to motivate new attitudes toward environmental concern in an industrial park case study.

The introduction of the **SPADE** methodology and the 6Cs meta-model for systems engineering represent innovations in the dialogue about the practice and application of systems engineering. First, the analysis and synthesis described in this thesis is the first time that so many of the traditional systems engineering methodologies have been compared side-by-side. Second, criteria for evaluating new systems engineering methodologies have resulted in **SPADE**, a streamlined methodology that is visually representative of the intrinsically iterative nature of systems engineering and at the same time free of jargon. The same side-by-side analysis supported the abstraction of six essential attributes of systems engineering, named the 6Cs meta-model of systems engineering enablement. This model is unprecedented because unlike most presentations of systems engineering activities that focus on the artifacts, this meta-model focuses on the abilities and overall contributions of the systems engineer.

This thesis also describes the application of both the methodology and the meta-model to a real-world case study. The conclusion drawn from the study is that the **SPADE** methodology makes the power of the systems engineering 'systematic' methods accessible to a wider audience of users. The abstract level of the 6Cs meta-model applied to the case helped to validate that 'systemic' systems engineering contributions can be made by persons other than professional systems engineers. This thesis establishes the usefulness of systems engineering in the domains of value chains and socio-technical systems.

The third contribution of this thesis is called the matrix of progress toward sustainable development, which was conceived as a visual mechanism to explain to business owners of small and medium enterprises how to improve their sustainable performance; that is improve simultaneously the social, economic and environmental practices of their firm. The matrix shows potential to make similar contributions at the regional and national level of assessment.

Preface/Acknowledgements

Indigenous peoples have become a stereotype for a “back to nature” movement that represents the sensitivity that industrial societies both envy and wish to emulate – without giving up their modern comforts. As Henry David Thoreau wrote, “What is the good of having a nice house without a decent planet to put it on?” But slogans and buzzwords will not result in the course adjustment so critical to the well-being of the planet. The solutions for planetary remediation will require advances in technology as well as new modes of social collaboration.

As a systems engineer, I look at all things in a context. I believe that thoughtful investigation of situations combined with comprehensive gathering of viewpoints from stakeholders is the only practical way to proceed. This journey of discovery has been about finding a way to make a personal contribution toward improving the world condition. There is much work remaining to be done. This research is just the beginning.

I have learned a few lessons from conducting this research. First, continuing as in past is unlikely to yield new results - we need to move from linear to circular practices to achieve continuous, step-wise improvement. And second, humans are too complex to specify every pathway to change – better to define a philosophy or use storytelling to describe the desired end result to help people find their own way to achieve objectives such as sustainability.

Many people have helped me arrive at this point. My thanks first to my parents; my father, who introduced me to systems approaches as a child and whose legacy is always with me, and my mother, who instilled in me the courage to stand up for my beliefs.

I owe a great deal of thanks to many people who have offered powerful encouragement throughout the process. Two people deserve special mention. My supervisor, Annik Magerholm Fet has provided academic advice, professional mentoring and her friendship. Terje Fossnes, my loving husband, has allowed me the freedom to pursue this degree as a full-time occupation and supported me with his encouragement, proof-reading and personal insights. Finally, thanks to the people of Verdal who have generously opened their community for observation, and especially to Stig Krokstad for his tutelage.

Trondheim, March, 2008

Cecilia Haskins

Cecilia Haskins

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1. Introduction

This section discusses the relevance of the research and the selection of research questions.

1.1 Background

The Norwegian University of Science and Technology (NTNU) is renowned for having one of the first university programs in Industrial Ecology (Marstrander et. al. 1999), which reinforces its reputation as a university that supports and encourages interdisciplinary research. This means there is no dearth of topics awaiting the PhD candidate when searching for a subject worthy of research. For a candidate with a background in systems engineering, information technology and industrial systems the options are broad indeed, and the need to conduct research across multiple disciplines is a necessity. The challenge was to find a topic that incorporated past knowledge, demanded new learning, and provided an opportunity to make a contribution to the world situation and the body of knowledge.

Eventually, the challenges of achieving sustainable development beginning from the starting point of today's legacy industrial systems inspired a set of research questions. Sustainable development, as is discussed later, has inspired decades of politicians, scientists and business leaders to work to create a world situation with a focus on international and intergenerational equity for all peoples. Thought leaders in the humanities, management and engineering disciplines have stressed repeatedly the importance of applying systems thinking and systems approaches to finding solutions.

The need for systems approaches is exacerbated by the high degree of networking enabled by today's internet technology, and the globalization of business that accentuates the connectedness of companies. This means that literally every firm must be viewed as just a part of a larger system that includes the neighbors in an industrial estate, cooperating companies in a value chain, national and international economic institutions, and finally the all encompassing natural environments of the planet. There has never been a greater demand for systems understanding and the dissemination and use of systems methods.

This thesis introduces systems methodologies, based on the principles and practices of systems engineering, and a contextual treatment of sustainable development that addresses the triad of equity, economy and the environment.

1.2 Main goal and research questions

The initial intention was to investigate the creation and maintenance of supply chains, to apply systems engineering practices, and to document the insights in a pattern language that both embodied systems engineering knowledge and would serve as a roadmap for firms setting out to create or manage a supply chain. The initial literature reading was indeed multidisciplinary, spanning systems theories, industrial ecology, supply chain management, and heuristics against the setting of eco-industrial parks (Haskins 2006).

The concepts and practice of Industrial Symbiosis, as demonstrated by the eco-park in Kalundborg, Denmark, suggested a refinement to the expansive domain of supply chain literature. In spite of the evolutionary nature of the inter-firm relationships in Denmark, it did not seem unreasonable to expect that future instantiations of eco-parks could be "engineered" (Haskins 2007).

Finally, while preparing to conduct a case study of Verdal, Norway, the final refinement revealed itself. Verdal is an excellent example of a town that built up as the result of globalization, only to face imminent destruction in the face of fickle international markets.

This suggested refining the research to focus on the following main objective,

Investigate the application of systems engineering to sustainable development as manifested in the creation and sustainment of an industrial park

All of the elements of this research objective are complex concepts: systems engineering, sustainable development and industrial parks. For this reason, the research needed to be organized to support progression toward concrete results. Eventually the research was defined by addressing the following questions, each of which is further discussed in the following sections:

Q1: how can systems engineering be applied to the creation and sustainment of an industrial park?

Q2: what are the principles of systems engineering that apply to socio-technical systems?

Q3: how is sustainable development positioned as a relevant objective for individual firms in an industrial park?

1.2.1 Systems engineering for socio-technical systems

The earliest authors in the domain of systems engineering (Hall 1962; Chestnut 1967) emphasized the importance of understanding the impact on the humans who use man-made technical systems, such as the telephone. Goode and Machol (1957), Ramo (1970) and Kossiakoff and Sweet (2003) each stress the significance of the fact that the early telecommunications engineers viewed the systems they created from a holistic perspective – as opposed to designing a handset independently from the infrastructure that supported the actual connections – and established standards that supported open competition while enforcing compliance (Martin 1999). The implications of doing otherwise can be inferred by looking at large technical solutions that are less friendly to humans, such as most city transportation services (Ramo 1970).

In order to consider the first two research questions it is necessary to establish a solid foundation for the systems engineering discipline itself and the scope of problems to which it applies. It is also important to establish the definition for system and socio-technical system.

A system can be defined as any entity that maintains its existence through the mutual interaction of its parts. This mutual interaction of the parts of a system give rise to behavior which is not characteristic of any of the individual parts; and, this property of systems is called emergence. Any system composed of both human and technical parts is a socio-technical system (Cook and Ferris, 2007). Socio-technical systems typically exhibit the highest frequency of emergent behaviors at the interfaces between the human and the technology (Parsons 2003). As an example, the IT profession is recognizing this shift in paradigm from stable to emergent IT systems. In this context, emergence recognizes that organizations are never fully formed, but rather in a constant state of transition. Such systems epitomize the meaning of continuous change; they are considered to be under constant development, adjustment and change, and unable to be fully specified as they meet the needs of the emerging organizations that they support. [Truex, Baskerville and Klein 1999]

Checkland (1999) felt compelled to invent his 'soft systems methodology' as a response to the deficiencies in early standards and documented practices of systems engineering when applied to socio-technical and social systems. The discipline has matured since then as evidenced by the issuance of an ISO standard (ISO/IEC 2002) and the frequent mention of soft methods, such as brainstorming, along side the hard skills of modeling and simulation

(Boardman and Sauser 2008). However, the perception persists that systems engineering methodologies are complicated and difficult to use (Haskins 2008b).

1.2.2 Industrial park development

Entities composing a product value chain are very often located in an industrial setting. This makes the development of industrial parks an important topic of research (Lowe 1997). The development of a park can be viewed from two perspectives; the individual relationships between the people and firms that are collocated in the park, and the more physical relationships in terms of movement of goods and materials between the occupants and their supply chain (to include both upstream and downstream relationships). In essence, an industrial park can be seen as a system with a life cycle, although one rarely finds literature that describes it in this way.

To answer the third question the research will become less theoretical and more empirical. Frameworks that emerge from the theoretical research will be used to explain the creation and development of industrial parks through both literature and a case study. This analysis will support the need for a simple mechanism to understand and communicate about sustainable development for the tenants of an industrial park.

1.2.3 Verdal Industrial Park – a case study

Verdal has already been the focus of many studies initiated from NTNU in cooperation with the local firms and the community (Carlsson 2001; Kvande; Kvarsvik; Opheim 2002). In October 2006, the university was contacted by Industri- og Produktutvikling AS (IndPro) to assist in a study of the current firms located in the Verdal Industrial Park as they prepared to plan their future activities to ensure the continued growth that has been typical of the past five years (Haskins 2007b). Empirical data gathered while working with Verdal Industrial Park is used throughout this thesis.

[Note: IndPro changed their name to Proneo in July 2007, but the original name used during the project is retained to minimize confusion with supporting documentation.]

1.3 Outcomes and structure of the thesis

1.3.1 Outcomes

The research progression spanned two years, beginning with an investigation into existing work and development of a methodology; application of the methodology in an empirical context; and, finally, development of a framework for visualizing progress toward sustainable development.

Restated, the main research objective addressed in this thesis is to "Investigate the application of systems engineering to sustainable development as manifested in the creation and sustainment of an industrial park." Figure 1-1 graphically illustrates the research questions, the related papers produced in the course of addressing these questions, and the major contributions of this thesis to the body of knowledge.

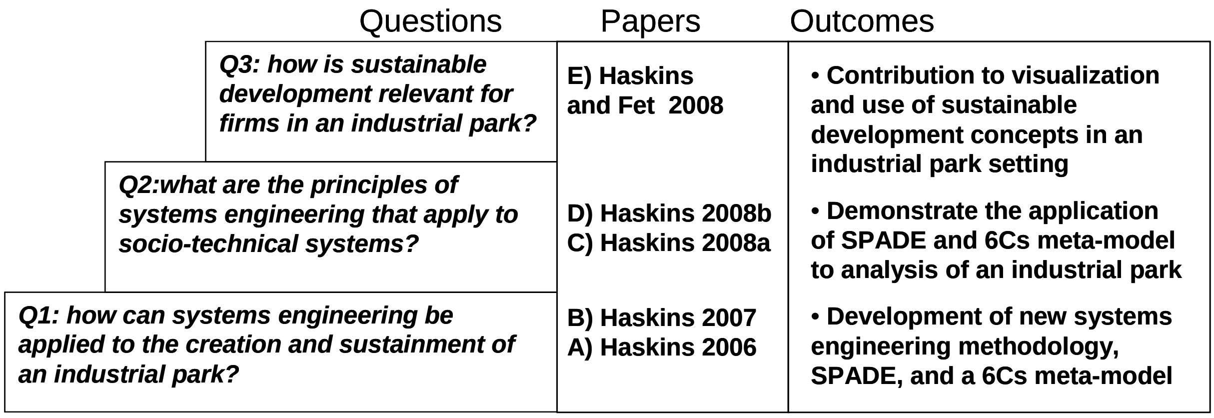

Figure 1-1: Research progression cross-referenced with papers and outcomes

The outcomes associated with this progression include five papers as listed in Table 1-1 and included in Appendix 1 of this thesis.

Table 1-1: Publication Artifacts

Id	Paper	Title
A	Haskins, 2006	Multidisciplinary investigation of eco-industrial parks
B	Haskins, 2007	A systems engineering framework for eco-industrial park formation
C	Haskins, 2008a	Using patterns to transition systems engineering from a technological to social context
D	Haskins, 2008b	Using systems engineering to address socio-technical global challenges
E	Haskins and Fet, 2008	Using the concept of sustainable development to encourage corporate responsibility in industrial park tenants – paper in progress

The initial investigation was written in a two part article (A and B, above). Part one used an eco-industrial park as the system of reference for analysis of the literature for relevant disciplines to support the research (Haskins 2006). Part two documented the categories and characteristics of industrial parks as discussed in the literature and introduced a systems engineering methodology for application to their creation and sustainment (Haskins 2007).

Haskins (2008a) addresses the nature of the traditional language of systems engineering discourse, derived primarily from technical engineering disciplines, and the limitations that this form of dialogue places on the application of systems engineering to solve problems of a non-technical nature. The paper illustrate this point by reporting on the participation of systems engineers in three workshops and their choice of organizational (soft) themes as the subject of the exercise.

Haskins (2008b) contains a critical assessment of systems engineering as a discipline and concludes that the training for systems engineers must extend to include skills that are necessary to support socio-technical systems, such as scenario building, and principled negotiations. An analysis of the most often-used systems engineering models is used to uncover the principles of systems engineering and derive a simplified methodology. Results of the analysis are then synthesized to extract the core values of systems engineering, which are presented as a meta-model of systems engineering enablement.

The final paper is a collaborative effort with Professor Annik Magerholm Fet and is currently in progress. This paper examines the discourse related to sustainable development and CSR and the corresponding foundations in environmental management reporting. Addressing the need to engage small and medium enterprises motivates the recommendation that the concept of sustainable development is useful for encouraging corporate responsibility. Data from the case study conducted in Verdal Industrial Park is reported.

1.3.2 Thesis contributions

The contributions of this thesis are three-fold; methodology development, abstraction of the methodology to a meta-model, and creation of a framework for explaining and understanding the progression to sustainable development.

A. First, the principles and practices of systems engineering are critically analyzed, reformulated and simplified into a methodology called **SPADE**. This methodology is introduced in section 4.1 and shown to have value in explaining the empirical data collected from Verdal as discussed in section 5.4.

B. Second, the top twelve systems engineering process models are synthesized, and a **6Cs** meta-model of systems engineering enablement is proposed. The advantage of this new meta-model is that it opens up the range of activities appropriate to systems engineering, and thereby the range of problems to which systems engineering is applied. This contribution is discussed in section 4.2 and applied to the case study in section 5.5.

C. Third, a framework for visualizing the stages of progression to sustainable development is derived from the experiences in Verdal. This framework is introduced and discussed further in section 6.

1.3.3 Structure of this thesis

The thesis has been structured as follows:

- Chapter 1 introduces the main objective and research questions of the thesis
- Chapter 2 provides a brief overview of the research methods employed
- Chapter 3 sets the theoretical foundations of the main research areas; namely, Systems Theory, Systems Engineering, Industrial Parks, and Sustainable Development
- Chapter 4 describes the contribution to the systems engineering body of knowledge; namely the **SPADE** methodology and the 6Cs meta-model
- Chapter 5 describes the case study and discusses the application of the systems engineering methodologies and meta-model
- Chapter 6 presents the evolution of the framework for sustainable development progress, which is a contribution to the sustainable development body of knowledge
- Chapter 7 contains a summary discussion of the research questions and outcomes, and identifies potential areas for future research.

2. Research methods

Kuhn warns the researcher that the way one is educated creates significant biases that influence the ability to see the world in new ways; to discover or invent (Kuhn 1962). This section briefly discusses the foundations of research, relevant methods, and the application of those methods to the research discussed in this thesis.

2.1 Background

Research begins with questions; questions for which the researcher does not have an answer (Mitchell and Jolley 1984). The biggest challenge is to choose a method of investigation that is most likely to yield a reliable foundation for finding an answer – if there is one.

The literature of research is filled with vocabulary that defines the parameters of philosophy, scope, and methods of research. In many cases, the language is polarized; quantitative versus qualitative. In other instances, the concepts are presented as a continuum; such as positivism, post positivism, critical theory, and constructivism.

2.1.1 Quantitative versus qualitative methods

Qualitative research can be characterized as the attempt to obtain an in-depth understanding of a situation as presented by informants, rather than the production of a quantitative measurement of its attributes or behavior (Wainwright 1997). Table 2-1 summarizes characteristics of each approach.

Table 2-1: Characteristics of qualitative and quantitative research

Characteristic	Qualitative	Quantitative
Goals	discover and understand observable phenomena	accumulation of observations that confirm existing theory
Paradigm	Phenomenological	Positivist
Point-of-view	Subjective	Objective
Sample size	Small	Large
Appropriate uses	building theory through inductive reasoning	verify theory through deductive reasoning
Methods (examples)	Case study, survey, interviews, content analysis	Simulation; multivariate statistical analysis

In the social sciences, large-sample, quantitative studies, such as multivariate statistical analysis, “attempt to freeze the social world into structured immobility and to reduce the role of human beings to elements subject to the influence of a more or less deterministic set of forces.” (Morgan and Smircich 1980: 498) But these mathematical methods have limited utility for studies in which the subject of investigation is not reduced to the restrictions imposed by a causal reality. This research must make effective use of techniques such as participant observation, content analysis, or in-depth interviewing, to name a few on the subjective-objective continuum proposed by Morgan and Smircich (1980).

Greckhamer et. al. (2008) reflect on the concept of interdisciplinarity within a system of disciplines, and conclude that a first step is to “transform the territory of knowledge production through communal action” via qualitative inquiry.

2.1.2 World-views summarized

Regarding the world-view, simplistically stated, a positivist world-view holds that the universe is deterministic and with enough observations, a theory can be derived to better predict and control it. Post-positivists reject this viewpoint outright. Because they recognize the inherent biases introduced into any study by the background of the researcher, post-positivists emphasize the importance of triangulation – the collection of corroborating data from multiple sources. Critical theorists also recognize that observation is fallible, and all theory is uncertain and subject to change. They hold that the best way to approximate ‘reality’ is by critical evaluation of each other’s work. The constructivists attempt to build their world-view based on their observations. This form of research begins with individual observations, followed by the emergence of patterns that eventually lead to the formation of theory (Creswell and Plano Clark 2007). The researcher’s challenge, therefore, is “to see what everybody else has seen and think what nobody else has thought.” (Quotation attributed to Dr. Albert Szent-Gyorgyi, Hungarian biochemist)

2.1.3 Analysis and synthesis

The scientific method can be described as an iterative dialectic between analysis and synthesis. Both terms derive from Greek and mean literally "to loosen up" and "to put together" respectively. Analysis and synthesis, as scientific methods, always complement one another (Ritchey 1991). The activity of analysis is associated with the collection of data relevant to the problem at hand; the activity of synthesis is putting together a cohesive whole and discarding anything that does not contribute. The cycle is repeated continuously until that which remains most closely explains real-world observations or is unchanged by the accumulation of new data. Suri (1998) asserts that the process of synthesizing research should be inductive and interpretive rather than following a rigid set of procedures and techniques. “The purpose of an interpretive synthesis of qualitative research is not to generate predictive theories, but to facilitate a fuller understanding of the phenomenon, context or culture under consideration.” (Suri 1998)

2.2 Empirical research

Empiricism (from the Greek for ‘based on experience’) is a commitment to obtaining knowledge through experience. This approach is contrasted with rationalism, which describes knowledge gained from thought or reasoning. Empirical methods are generally characterized by the collection of data and drawing conclusions based on the observations. Selecting a research method for empirical research is problematic because the benefits and challenges to using each method are not fully catalogued (Easterbrook, et. al. 2007). For example, the researcher can choose from a variety of data collection instruments ranging from direct observation, to questionnaires, and including archival data research. Triangulation of results would occur with overlapping data collection from each type of source.

In the evolution of research methodologies, mixed methods can be thought to follow first the quantitative, and then the qualitative approaches as a third research movement (Creswell and Plano Clark 2007). Mixed methods research has evolved to address the complexity of real-world research problems, which require answers beyond what quantitative numbers or qualitative words can provide alone. In mixed methods research, each method used should compensate for the weaknesses of the others (Easterbrook, et. al. 2007).

2.2.1 Empirical research in systems engineering

The literature is in general agreement that social sciences are different from natural sciences in three distinct ways. First, conclusions about social phenomenon are subject to the individual interpretation of the observer; unlike a litmus test in which the paper turns either red or blue depending on the pH factor. Second, the object of study is the human being, sometimes depersonalized as an 'actor' playing a 'role' in the larger context, like cogs in a machine. Third, this object of study defies all attempts at consistent predictions about its behavior; unlike the litmus paper that is always blue in alkaline conditions. (Checkland 1999; Forrester 1998; Warfield 1976)

In reality, a system is nothing more than a way of looking at the world, or a point of view (Weinberg 2001; Martin 2007). Bergner (1981) understands this when he summarizes social science research as follows:

> *The disciplines and the schools in them are not thought to have different 'areas' to study. Rather, each studies the same total social-political-economic-historical reality, but from its own 'perspective.' … each school approaches the same massive and complex reality, but from a different vantage point. For this reason, it might be said that there are no self-evident boundaries between the social sciences and the various 'interdisciplinary' approaches which have sprung up alongside them. (Ibid: 2-3)*

One of the main goals of General Systems Theory was to promote interdisciplinary cooperation by improving the communication between specialists (von Bertalanffy 1968). "Complementarism is a way of understanding complex phenomena using more than one perspective … by using the widest possible set of systemic images, metaphors, and methodologies." (Solem 2003) Systems engineering research is served best by interdisciplinary approaches (Haskins 2006; 2008b). This suggests that research within systems engineering should include a variety of methods ranging from mathematical modeling and simulation to case studies including surveys and interviews. Mixed methods research is pluralistic, pragmatic, and situational; focuses on 'what works' and real-world practice (Creswell and Plano Clark 2007; Greene 2008), which makes it ideally suited to the systems engineering research agenda.

Valerdi and Davidz (2007) assert that it is essential to ground systems engineering in empirical observations despite the lack of appreciation for these methods motivated by the biases of 'engineering' toward the positivist, quantitative research paradigm. This bias overlooks the evidence that many problems addressed by systems engineering are socio-technical issues (Kroes, et. al. 2006; Frank and Waks 2001; Cook and Ferris 2007). They conclude that the use of empirical mixed methods will improve the quality of research, advance the maturity, and improve the understanding of systems engineering. Martin and Davidz (2007) offer advice to researchers in systems engineering on the process for developing a case study.

2.2.2 Empirical research in sustainable development

Van Kleef and Roome (2007) propose that the research agenda for sustainable business management requires additional empirical studies to construct models that provide guidelines to teams, organizations and networks of organizations that wish to adopt a more sustainable pattern of production and consumption. Business communities are social systems made up of real people constantly faced with a complex network of choices (Haskins 2006). If you change the ideas in a social system, you change the system itself (Forrester 1998).

Kruijsen (1998) asserts that investigation into sustainable development should focus on both the creation of new theory as well as methods for realizing sustainable development; that is, the researcher must be concerned with solving both the theoretical problem as well as the practical one. In her guidelines, she emphasizes the contribution of multiple perspectives, and the importance of realizing that the path to sustainable development is not well-paved and investigations must be permitted to rely on the experience of the researcher and practitioner.

When little is known about a phenomenon – such as the relevance of sustainable development to the tenants of an industrial park – current perspectives have little empirical substantiation. Theory building from case study research is appropriate because it does not rely on previous literature or prior empirical evidence; "… building theory from case study research is most appropriate in early stages of research on a topic or to provide freshness in perspective to an already researched topic… theory-building research should result in new insights." (Eisenhardt 1989: 548)

2.3 Systematic Inquiry

Sociologists Glaser and Strauss (1967) established a new scientific method for the inductive discovery of theory grounded in systematically analyzed data, originally called the 'constant comparative method of qualitative analysis,' shortened to Grounded Theory. This method derives its foundations from American pragmatism and is primarily concerned with understanding action from the perspective of the human agent (Haig 1995).

Grounded theory research begins with the researcher choosing an area of focus without preconceptions. Next, data is gathered from a variety of sources which may include interviews, survey results, or data from a body of knowledge. As the data is gathered it is coded (labeled and categorized), analyzed and interpreted, eventually leading to new theories (Easterbrook, 2007). Haig (1995) presents grounded theory as a scientific method concerned with the detection and explanation of social phenomena. Glaser and Strauss (1967) encouraged both new and established practitioners to conduct grounded theory research.

2.4 Case Study

The case study is used to contribute to our knowledge of situational phenomena because it allows the investigator to retain the "holistic and meaningful characteristics of real-world events" – such as organizational and managerial processes and the maturation of an industrial area (Yin 2003: 2). This research method is relevant for questions of 'how?' or 'why?' in a contemporary setting, when the behaviors of the participants can not be manipulated. A strength of the case study is its ability to encompass the collection of a variety of evidence – documents, artifacts, interviews, and observations – which supports triangulation of the results. For example, constructing a chronology of events over time serves both a descriptive and analytical purpose within the case study (Yin 2003). Furthermore, case study research is not uniquely supported by quantitative or qualitative methods; nor is it the exclusive domain of any world view. A positivist researcher will look for generalizable theory, whereas a post-positivist or constructionist will be interested in the evaluation of rich case descriptions.

Yin (2003) identified five different applications of case study research; explain, describe, illustrate, explore, and meta-evaluation. In each instance, the project sponsor will have a prominent role in the definition of the case study – not just the researcher alone.

A case study may focus on a single or multiple populations for study. The more diverse the sampling, the more likely the results will support eventual generalization. The investigator is advised to avoid drawing general conclusions from limited data (Suri 1998).

2.4.1 Survey research

Sapsford (2007) defines the survey as a research style that involves systematic observation or interviews on a real-world population. Survey research can be conducted in a variety of formats; questionnaires, psychological tests and interviews (Mitchell and Jolley 1984). An advantage of surveys its ability to gather information from a large sample with less effort than other techniques. With careful construction, a survey can help develop a profile of the respondents – for example, what are their attitudes, shared demographics (Warren 1965).

However, responses need to be validated, and it is not adviseable to trust answers that are too much about the past or the future. The temptation to infer causality from the results is considered a weakness of survey research. And since typical response rates are low, and the respondents themselves are self-selected, the data may not be representative of the original populaiton (Sapsford 2007).

Mitchell and Jolley (1984) identify three types of interviews; structured, semi-structured and unstructured. In structured interviews, the same questions are administered to all subjects. Semi-structured interviews begin with a core of standard questions, but the interviewer may expand on any question for additional depth. Unstructured interviews are most vulnerable to interviewer bias and the collected script is usually too disorganized for subsequent analysis. Hove and Anda (2005) offer good advice to researchers planning to conduct semi-structured interviews.

2.4.2 Action research

Action research refers to a continuous process of research and learning that takes place during a researcher's long-term relationship with a problem. The process is highly iterative; intervals of activities include planning, action, observing and critical reflection. Action research is described as a cooperative form of inquiry; 'learning together' and research 'with' rather than 'on' people (Reason and Bradbury 2006).

Action research is interventionist because the researcher tries to improve the situation currently under observation (Mirata 2005). The history of applying action research with a socio-ecological perspective is presented in Flood (2001). Ballard (2005) reports on his use of action research methodology to promote changes for sustainable development in a healthcare institution. Action research is very effective for use by researchers investigating questions at the same time that they are deliberately influencing the actions taken, and thereby the results. Action research is also effective for finding new understanding, developing new practices, and when formal statistical analysis is not used (Stringer 2007). The highly iterative nature of action research projects requires longitudinal interaction (measured in years, not months) between the researcher and the participants.

2.5 Methodology, meta-model and framework

2.5.1 Definition of terms

A number of terms will be used throughout this thesis and are worthy of definition. Both the Merriam-Webster and Oxford English Dictionary online versions were used to establish a baseline definition for the words. Table 2-2 contains a short glossary of important terms.

Table 2-2: Glossary of important terms

Framework	• a supporting or underlying structure
Meta-	• more comprehensive : transcending • something of a higher or second-order kind
Methodology	• a body of methods, rules, and postulates employed by a discipline • a particular procedure or set of procedures
Model	• representation of a person or thing • a description or analogy used to help visualize something that cannot be directly observed
Theory	• a belief, policy, or procedure proposed as the basis of action • a plausible or scientifically acceptable general principle or body of principles offered to explain phenomena

Models are, at best, “a caricature of reality” and the main role of models is not so much to explain and to predict as to polarize thinking and to pose sharp questions (Kac 1969). Meta-models are used to describe and analyze the relations between concepts, and provide a set of rules for how a domain-specific model is built; a model about a model. The purpose of methodologies is to provide repeatable approaches for doing something well, based on established techniques. Methodologies focus on both the processes and the artefacts of the relevant techniques. Therefore, a well-constructed methodology also provides a structure, or framework, upon which to evaluate the results achieved by following the guidelines of the recommended methods. The framework provides support for further development of the methodology in areas where the current methods are immature or insufficient.

2.5.2 Reasoning approaches and theory

Deductive reasoning begins from a base of theoretical knowledge, derives new theory from this background and uses empirical testing to support conclusions to accept or reject the new theory (Kovács and Spens 2005). Inductive reasoning begins with zero or limited theoretical knowledge from prior research, studies the data from real-world observations, and derives theoretical conclusions or frameworks from the observations (Kovács and Spens 2005). Abduction occurs when individual phenomenon are interpreted or re-contextualized from the perspective of a new conceptual framework (Dubois and Gadde 2002). All three approaches were used throughout this research.

2.6 Application of the methods

The research proposed for this thesis required the use of rational and empirical methods. The research questions provided a focus and a filter for the volume of data collected over the years. A constructivist approach was used within the established constraints of systems engineering principles; reasoning about the data collected was used to create novel theories that explain the past and prescribe ways that systems engineering practices can influence the future.

The researcher’s analysis and synthesis of systems engineering was based on a priori knowledge from decades of real-world experience combined with extensive literature review. The research into sustainable development was conducted as a case study with a survey. The empirical research methods have been applied according to the principles of Mixed Methods Research (Creswall and Plano Clark 2007). Specifically the ‘sequential explanatory strategy’ has been applied. Using this strategy, results from the quantitative data collection phase (survey) are explained and interpreted by the data collected during the qualitative phase (interviews).

2.6.1 Questionnaire and Interviews

Questionnaires are either self-administered or investigator-administered. Both forms were used; first, a pilot version of the questionnaire was administered with the investigator at hand to clarify questions and record suggestions for improvement. Then, after implementing some minor refinements, the final version of the questionnaire was administered using an online tool. Face-to-face interviews were scheduled later with a representative cross-section of the respondent population to assess the validity of the answers, and to add to the richness of understanding about the CEO’s attitudes toward sustainable development.

Today’s online survey tools support all of the most common question structures. The final survey included questions using the Likert-type scale to measure the importance of a set of social and environmental activities within the firm. The only binary construction was the question asking whether the respondent was willing to be interviewed (yes/no). Most of the questions offered fixed alternatives from which the respondent could choose. These questions were always accompanied by a small textual field to collect a specific response that the respondent felt was otherwise not represented by the questionnaire options. Some of the questions collected nominal data, for example, regarding how long the firm had been located in the industrial park, and the scope of purchasing and sales (local, regional, national or international).

This researcher conducted one-hour semi-structured interviews from a set of prepared questions. However, most of the interviews took the form of a conversation around the theme of the questions. The subjects were all very relaxed and imparted many valuable insights to the researcher. On one occasion, the interview extended to two hours. Since interviews are an oral activity, the questions were also typed out in Norwegian to ensure that the interviewee understood the meaning of the question.

Since the interviews took place within the context of a case study, the investigator took advantage of ad hoc data collection opportunities by adding additional interviews of regional leaders, and adding observational evidence by attending a town-hall meeting on the subject of the pollution effects of a new limestone-burning oven (Eisenhardt 1989).

2.6.2 Grounded Theory

Haskins (2008b) describes the researcher's use of grounded theory. The article includes an example of the coding logic used to derive the final set of thirty-eight systems engineering activities. Limited coding was also performed on the interviews using categories suggested by research reports from the UK Department of Trade and Industry (DTI 2004). As an example of the former, when being informed for the first time about the principles of sustainable development, those who had never heard of the term would express their status with a sentence like, "I was not aware of that before." From this expression, the term Awareness was derived to indicate moving from a state of non-awareness to being or becoming aware of sustainable development.

2.7 Future research

The questionnaire asked respondents to evaluate their relationship with every other firm in the park. Evaluation of this data is outside the scope of this project. The relationships will be evaluated at a later date using a tool such as social network analysis (Breiger 2004; Newman 2003). This form of analysis may help uncover potential synergies and currently lost opportunities for inter-firm cooperation.

Because there was some intervention on the part of the researcher, action research methods could have been appropriate for this study had there been more time available to create initiatives and follow through after the initial survey. This methodology will be considered for future research investigations/interventions that involve helping firms assess their current status and implement changes to achieve sustainable development.

3. Theoretical Foundations

This section provides some background discussion of the practice and discipline of systems engineering as revealed by the body of knowledge, and the underlying foundations in systems theory.

3.1 Systems theory

Checkland (1999) and Warfield (2006) offer thorough histories of systems thinking in Western Civilization back to the early Greeks. Up until the 1940s, the traditional scientific methods championed by Descartes, Bacon and Newton had proved useful models for understanding the universe. Whenever a concept was too large to comprehend in its entirety, it was decomposed or reduced to simple elements – hence the moniker reductionism. A new school of thinkers challenged this approach with a more holistic, or 'constructionist' point of view. General Systems Theory (GST) fulfils a transdisciplinary role by bringing together theoretical principles and concepts from ontology, philosophy of science, physics, biology and engineering. Systems theory has its roots in the writings of Ludwig von Bertalanffy, Anatol Rapoport, Kenneth E. Boulding, William Ross Ashby, Margaret Mead, Gregory Bateson and others (ISSS 2007).

The view is called constructionist because rather than breaking down a system under investigation into progressively smaller parts, systems thinking proposes expanding the viewpoint to take into account larger and larger numbers of interactions as an issue, problem or system is being studied. Using this approach, it should be possible to identify the dynamic behavior and study the systemic interrelationships, and establish patterns of interactions and change, which taken together provide a more complete understanding of how things work. The constructionist approach suggests the importance of understanding a system from many viewpoints. The ability to do so is dependent on ones ability to integrate knowledge from multiple disciplines to understand the subject of investigation. Understanding and solving today's complex problems, such as man-induced climate change, require the contributions of diverse scientists, politicians and the world community. Indeed, multidisciplinary integration is the buzzword of the 21st century (Pain 2003).

Systems theory is the underlying foundation for many tools of investigation, analysis, and creation. Checkland's Soft Systems Methodology, Forrester's Systems Dynamics, problem resolution techniques (Christakis 1996) and the practices of Systems Engineering all derive from the principles of GST. Kurt Richardson summarized the primary role of GST in this way, "A major role for any GST was to facilitate communication between disparate fields of interest, i.e., to provide a common language with which to discuss systemic problems." (Richardson 2004; 127)

Two topics will be further embellished because of their frequent reference in this research; they are system dynamics and social systems thinking.

3.1.1 System Dynamics

Systems thinking developed as a response to the rapid increases in technological complexities that confronted engineering and science after the Second World War. In the 1960's, Jay Forrester developed a branch of systems thinking which focused on organizational change and was eventually referred to as system dynamics. The very term implies that constant change within socio-technical systems is assured, which means that the methods have been found useful for a broad range of analysis. System dynamics diagrams have been used to analyze behaviors as divergent as the entire planet in the World Model (Meadows, et. al. 1992; Myrtveit 2005) and the trust between two organizational entities (Kurstedt 2003). Both models reflect the integration of knowledge from multiple disciplines. More importantly, according to Forrester, system dynamics models can capture the rich body of knowledge held by people in the real world. These models can demonstrate the circular processes in which each decision causes changes that in turn influence future decisions (Forrester 1998). Forrester suggests that science and technology are no longer at the frontier of human advancement because they have become ubiquitous in the fabric of every day life. Rather he proposes that social system design is the next frontier, which will lead in turn to a better understanding of man-made social and economic systems (ibid).

3.1.2 Social Systems Thinking

It is critical at this point to emphasize that the concept of a 'system' is a communications device; systems are more cognitive than real (Checkland 1999; Martin 2007; Beer 1961). No two persons will ever share exactly the same understanding of a 'system' because personal values and ways of thinking will differ with each individual. This is further complicated by the notion that each system possesses three different viewpoints of interpretation; the structural or hierarchical view, the behavioral or functional view, and the social or relationships view (Banathy 1996). In addition, people are suspicious that any discussion of social 'systems' implies a loss of freedom for the human agent within the system. Suggesting that the solutions to social problems can be 'engineered' has the potential to create misconceptions. The term 'social engineering' is associated with many negative connotations. It brings up visions of manipulative adverting campaigns, propaganda in the hands of authoritarian governments, and scamming users in cyberspace (Matejko 1997). Authors, such as Banathy (1996) and Warfield (2006), use the term 'systems science' when applying the systems approach to social systems.

Checkland (1999) criticized the formal systems methods approach – i.e. working to achieve results against a pre-defined objective – as unsuitable for social problems. However, as the nature of the 'hard' systems has increased in complexity and uncertainty, systems engineering has, of necessity, needed to evolve as a discipline able to cope with imprecise objectives and the challenges of emergent behavior in man-made systems (Cook and Ferris 2007). For this reason, the lines between 'hard' and 'soft' systems can be said to merge into one as the systems under consideration become more complex and fuzzy. Methods for designing the structure and underlying policies of human systems are improving, such that these systems will better serve the people within them (Forrester 1998). A proliferation of methodologies have been devised to address this need; Viable Systems Model (Beer 1985), Total Systems Intervention (Flood and Jackson 1991), and Idealized Design (Ackoff, et. al. 2006).

An entire field of research has built up to address complexity in mathematics, physics, computer science and biology, but this type of complexity is not the focus of this thesis. However, there are many overlapping themes between complex systems science and social science (Andrus 2005).

Advances in the study of social systems design are critical. As Banathy sums it up, "… we are entering the twenty-first century with organizations designed during the nineteenth. Improvement or restructuring of existing systems, based on the design of the industrial machine age, does not work anymore." (Banathy 1996: 1) Like Forrester, Banathy believes that the design of social systems is a future-creating activity, in which the participating humans "coevolve with the emerged realities and expectations for their environment." (ibid) The significance of this viewpoint is demonstrated in Haskins and Fet (2008).

3.2 Systems engineering

3.2.1 Systems Engineering – an historical perspective

The first book published with the term systems engineering in the title was Goode and Machol's '*System Engineering: An Introduction to the Design of Large-Scale Systems'* from 1957. As is typical of engineering disciplines, systems engineering had already been practiced by Bell Laboratories and others for more than a decade (Hall 1962; Checkland 1999; Ferris 2007).

Two concepts are essential to understanding the broad scope of systems engineering. The first, systematic, refers to an attribute of the scientific method. Being systematic means taking a thorough, orderly approach to solving a problem or set of problems. The second concept is that of systemic. The term means "of the whole body" and its use implies a holistic appreciation of the object under consideration, whether a man-made engineered system or an international political effort toward reduction of climate gases emissions.

Systems engineering is described as both 'systematic' and 'systemic' (Chestnut 1967). On the one hand, the literature of systems engineering describes a variety of systematic processes for developing, designing, and deploying large-scale complex systems (Haskins 2008b). On the other hand, successful systems engineering must be built on a foundation of systemic thinking to conceive and solve complex problems.

Figure 3-1 contains a time line of standards for systems engineering (INCOSE 2004). USA Military Standard 499: Systems Engineering (Mil-Std 499) is the first documented systems engineering standard and was used to guide the early defense programs in the USA. Early standards were very detailed with a focus on the development and verification of systems. Newer standards cover more of the total system lifecycle, and standards currently in progress are focused on integrating software engineering processes (Boehm 2006). See Appendix 1 of this thesis for the title of other standards not spelled out here.

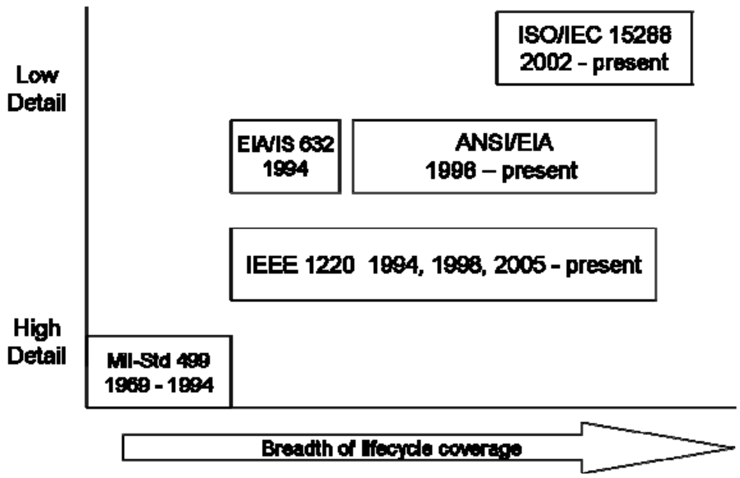

Figure 3-1: Timeline of standards for systems engineering

The illustration in Figure 3-2 is the recommended systems engineering processes taken from Mil-Std 499. This view has survived the test of time, and is still used today as an easy encapsulation of a generic systems engineering process.

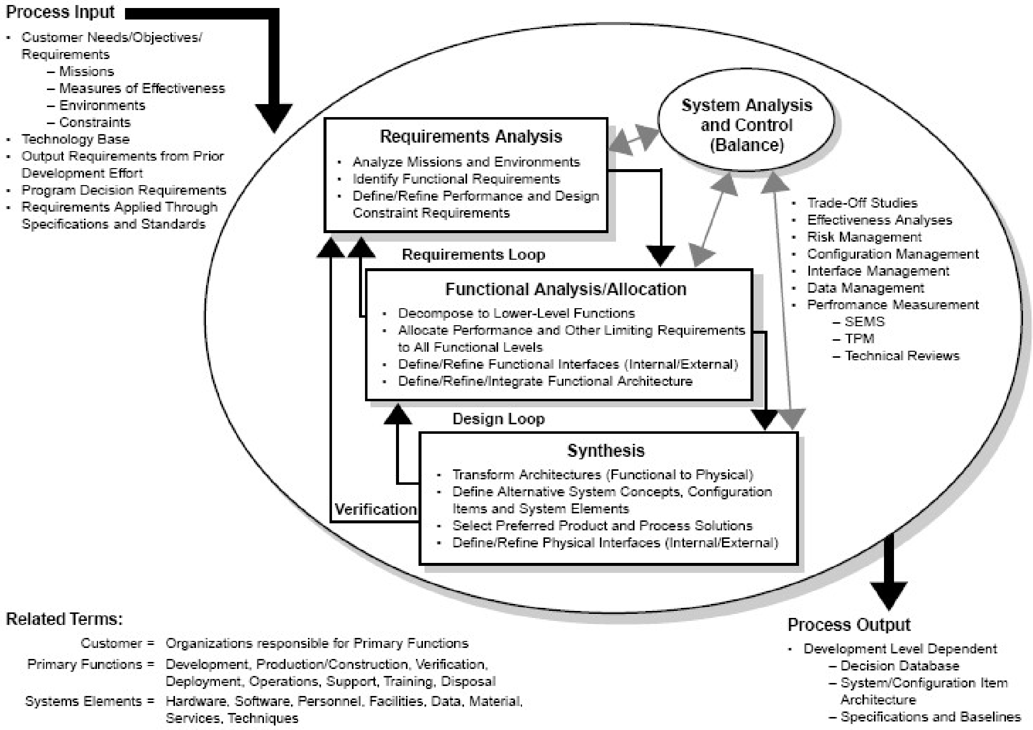

Figure 3-2: Early view of the systems engineering processes (USAF, 1969)

In 1990, a group of leaders in the profession of systems engineering met to discuss the future of the profession. The result was the formation of the International Council on Systems Engineering (INCOSE), representing practitioners, educators and researchers. INCOSE is the premier organization for the definition and dissemination of systems engineering practices (Honour 1998; Brill 1998). At the time of formation, a diversity of viewpoints and definitions for the term systems engineering existed. For example, Professor M'Pherson defined systems engineering as "… a hybrid methodology that combines policy analysis, design and management. It aims to ensure that a complex man-made system, selected from the range of options on offer, is the one most likely to satisfy the owner's objectives in the context of the long-term future operational or market environments" (M'Pherson 1986; 330-331). It was not until 1996 that INCOSE approved a definition that represents a compromise position: *Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems* (Haskins 2006b: 1.5). Here, the word 'realization' is intended to encompass more than the development cycle to include a whole-life perspective of the system of interest.

In 2002, the first (and currently only) international standard on systems engineering was ratified and issued. The INCOSE Systems Engineering Handbook (SEH; Haskins, 2006b) embellishes the guidance of the international standard entitled *ISO/IEC 15288:2002(E) – Systems Engineering – System Lifecycle Processes*. The standard categorizes the systems engineering processes as follows: Enterprise, Acquisition, Project and Technical Processes. Figure 3-3 illustrates the processes by category. The SEH further defines activities relevant to each process, their interrelationships, and enabling methods and tools.

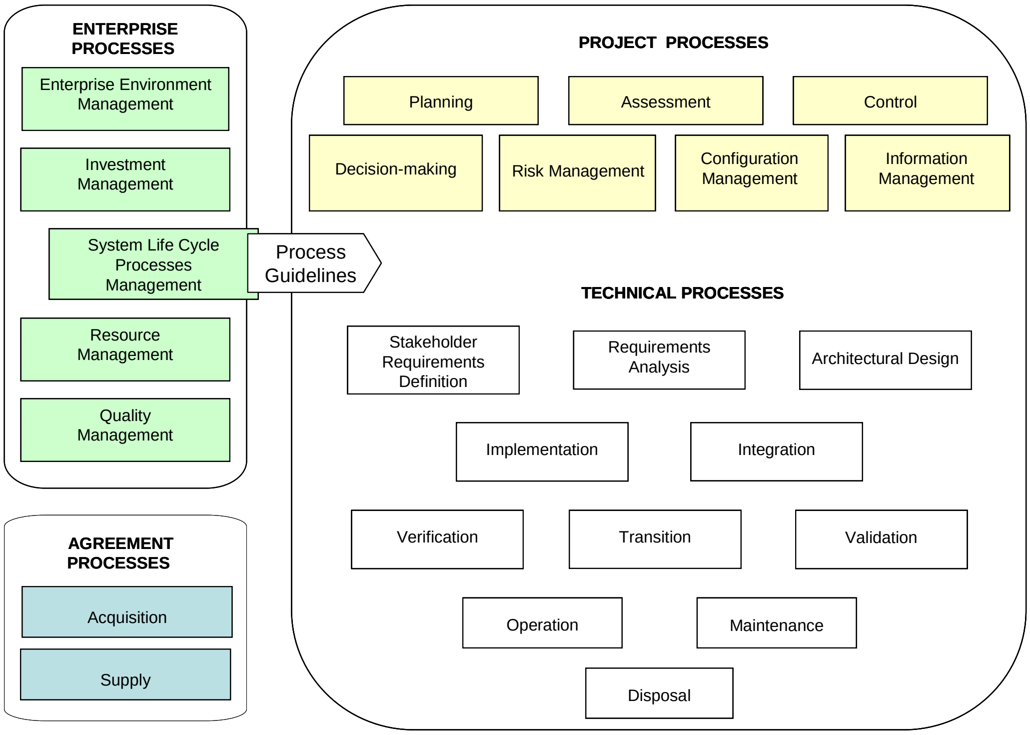

Figure 3-3: Systems Engineering Lifecycle Processes (Haskins, 2006b)

A concept map representing the ontology of systems engineering is shown in Figure 3-4 (Bahill et. al. 2002). The advantage of this view over Figure 3-2 is that the ontology is industry and application independent and puts the focus on the critical elements of systems engineering. Another advantage of such a mapping over the traditional views is that the temptation to visualize systems engineering as a set of linear processes is avoided and the reader can focus on the relationships as shown. Perhaps the most significant contribution of the ontology is the definition of systems engineering as a structured discovery process (see the lower right corner).

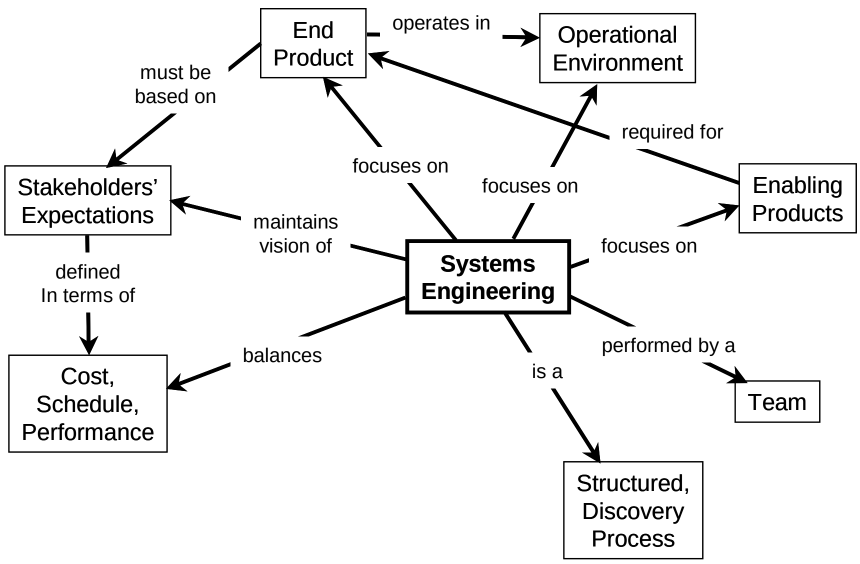

Figure 3.4: Systems Engineering Concept Map, (Bahill, et. al. 2002)

The systems engineering body of knowledge has been building rapidly since the formation of the INCOSE. In addition to many new books authored on the subject, the body of knowledge includes proceedings from the INCOSE symposia and regional conferences since 1991, the peer-reviewed journal *Systems Engineering*, and the technical content of the quarterly newsletter *INSIGHT*. This body of literature includes empirical contributions from practitioners, research results from academia, and general debate on the value and scope of systems engineering. However, it should be noted that the contributions have been made primarily by the current INCOSE membership whose demographics are skewed toward persons employed by military, aerospace and heavy industries, such as automotive. As a result, the literature maintained by the INCOSE needs more empirical or research contributions on the subject of the application of systems engineering to problem-solving for the large, complex global socio-technical issues confronting mankind today (Haskins 2008b; Levy et. al., 1998).

The body of knowledge also includes the PhD research that expands the understanding of systems engineering as a discipline. Included on this list are two theses from NTNU (Fet 1997; Dahl 2001).

3.2.2 Systems Engineering extensions

MIT has proposed that the discipline of systems engineering is really a subset of a newly defined field they have dubbed Engineering Systems (Rhodes and Hastings, 2004). They define Engineering Systems as a superset of disciplines incorporating both engineering and management sciences and including Systems Engineering. This new field of Engineering Systems addresses some of the criticisms levied against systems engineering and expands the scope to encompass the development of "sustainable engineering systems with optimized value to society as a whole." (Ibid: 4) In this context, systems engineering is applied to socio-technical systems.

Recent entries into the body of knowledge extend systems engineering practices into enterprise engineering (Faisandier 2005) and socio-technical systems (Ottens, et. al.; Kuras and White 2005). Hitchins (2007) proposes a five-level nested model of systems engineering, shown in Figure 3-5, through which systems science is applied to bridge the gulf between the problem and solution spaces. Each layer "lives within", and contributes to, the one above as the societal perspective increases. Each layer is associated with its own processes and methods.

A very brief summary of the five-layer model is given as follows:

Layer 1 – Product systems engineering – this is the layer in which artifacts are produced, and corresponds with traditional systems engineering processes described in section 3.2.1.

Layer 2 – Project systems engineering – this is the layer that is concerned with the management of the project and the product (or system) lifecycle.

Layer 3 – Business systems engineering – this layer is concerned with production (or assembly) of the product and the eventual sale and distribution of the product; more than one firm may contribute to the processes at this layer.

Layer 4 – Supply Chain (or Industrial) systems engineering – this layer expands the involvement of upstream and downstream companies; multiple products will be considered in this layer.

Layer 5 – Socio-economic systems engineering – this layer introduces influences from governmental and economic institutions in the form of regulations and monetary flows; societal impacts will be considered in this layer.

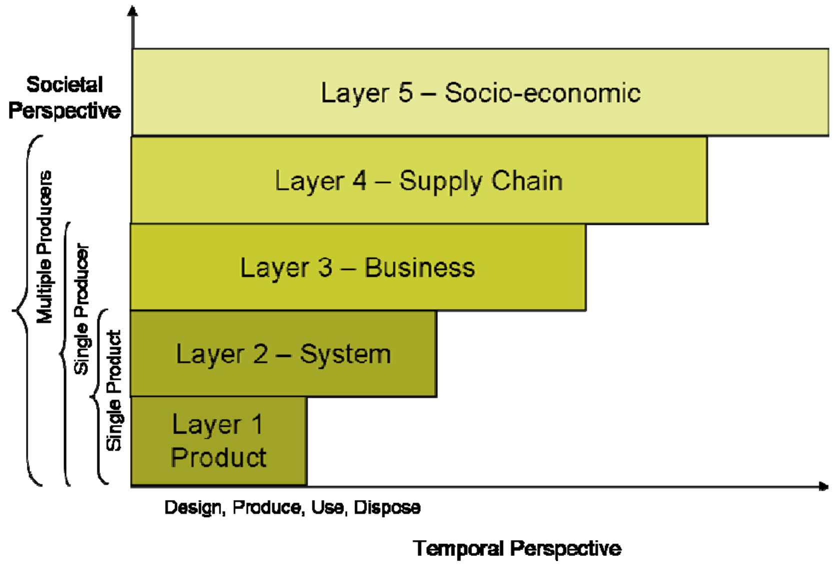

Figure 3-5: Hitchins five-layer model (based on Hitchins 2007)

This model corresponds closely with the model of levels of environmental performance derived by Fet (1997) and shown in Figure 3-6. The horizontal axis is the time span of a product's lifetime with its phases planning, manufacturing, use and disposal, and then the human lifetime extending to the intergenerational span of civilization. The vertical axis indicates the scope of the environmental concern, ranging from a single product life cycle, to all the products made by one manufacturer, gradually encompassing all manufacturers and the whole of society.

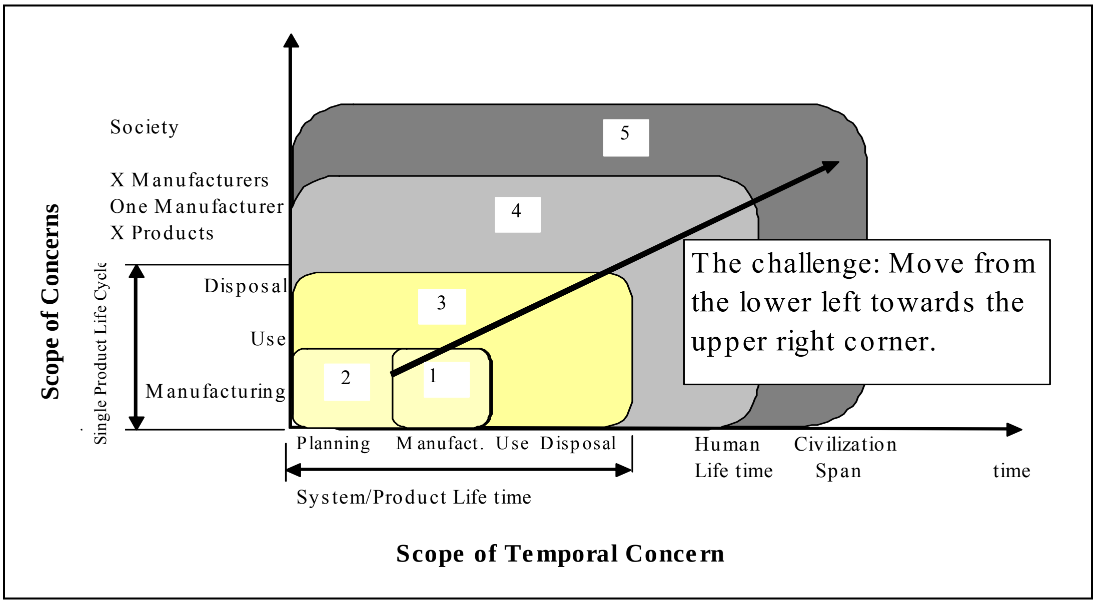

Figure 3-6: Classification of environmental performance levels (Fet 1997)

The shaded and numbered areas represent the scope of environmental performance at different levels:

1. Environmental Engineering (includes various types of engineering and production) – corresponds to Hitchins layer 2;

2. Pollution Prevention (limited to product production and planning) – corresponds to Hitchins layer 1;

3. Environmental Conscious Design and Manufacturing (concerns the entire life cycle of a product including the distribution, the use and end of life treatment of the product) – corresponds to Hitchins layer 3;

4. Industrial Ecology (concerning several producers in a long term perspective, e.g. an industrial park located in a region, or a chain of suppliers) – corresponds to Hitchins layer 4;

5. Sustainable Development – corresponds to Hitchins layer 5. As shown, sustainable development is concerned with the environmental impact of any activity on society as measured in the span of human history. A sustainable industrial park, for example, would be expected to survive many generations, with a cumulative positive impact on society.

3.3 Industrial parks and sustainable development

3.3.1 The life cycle of industrial parks

The industrial revolution is a concept that represents the social, political and economic changes that took place as people, first in England, and later in the USA and other parts of Europe, left their farms and cottage industry (home crafts) to flock to the (urban) factories. Stories from the earliest days expound the horrors of child labor and sweat shops, where man was subservient to machine, and the factories spewed smoke and debris into the air and water that their workers would breath and drink. Gradually these conditions have improved, but there is still room for improvement in the way most companies interact with people and the natural environment. For example, many nations have recognized the need to encourage the development of low-carbon or no-carbon technologies needed to wean their economies off fossil fuels. In theory, the wealth and the jobs created by these ‘green’ technologies should help to offset the costs of reducing carbon emissions (Prugh 2008).

Principles of industrial ecology, in which industry mimics nature, are often applied when discussing stewardship of the planet. A basic premise of Industrial Ecology is that as humans, we should model our systems after natural ones if we want them to be sustainable. In mimicking Nature we will minimize the harmful waste that we create and maximize the use of waste and products at the end of their useful lives such that they become the inputs to new processes and industries – a chain that is often referred to as spanning “from cradle to rebirth” versus the more typical “cradle to grave” lifecycle (Ausubel 1998). This new paradigm presumes a change in the nature of industrialization from the traditional (polluting) methods to a full industrial ecology, as illustrated in figure 3-7, whereby all systems and production plants will eventually be fully compatible with existing industrial ecosystems as a matter of course (Little 1991).

The literature is filled with examples of rampant use of the concept of the “nth industrial revolution” where one source dubs nano-technology as the sixth industrial revolution and self-replicating machines as the seventh (Walker 1990). There is general consensus that engineering, science, and computing have each heralded an age of change, which if not revolutionary, was significant enough in its impact on where and how people live. It is interesting to place the emergence of industrial ecology against the broader context of the industrial revolution and its many phases. Figure 3-8 graphically illustrates the stages of industrial revolution and categorizes the various innovations enabled by computing under a single stage labelled ‘continuous innovation’ to designate the shortened windows of exploitation opportunity and increasing rate of change enabled by computers (Valery 1999). In fact, it is questionable whether it is appropriate to refer to the quiet changes motivated since the advent of the computer as ‘industrial’ revolutions. However, the sophisticated automation used to realize advances in cleaner production are enabled by advances in computing and artificial intelligence (Pineda-Henson and Culaba 2002), at the same time that they create greater demands for energy (Thomas 2006).

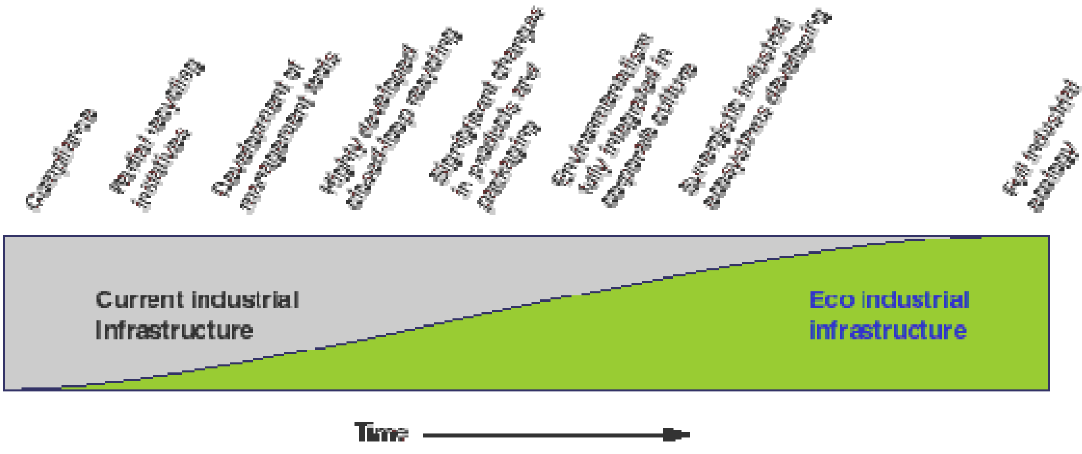

Figure 3-7: The Emergence of an Eco-Industrial Infrastructure (Little, 1991)

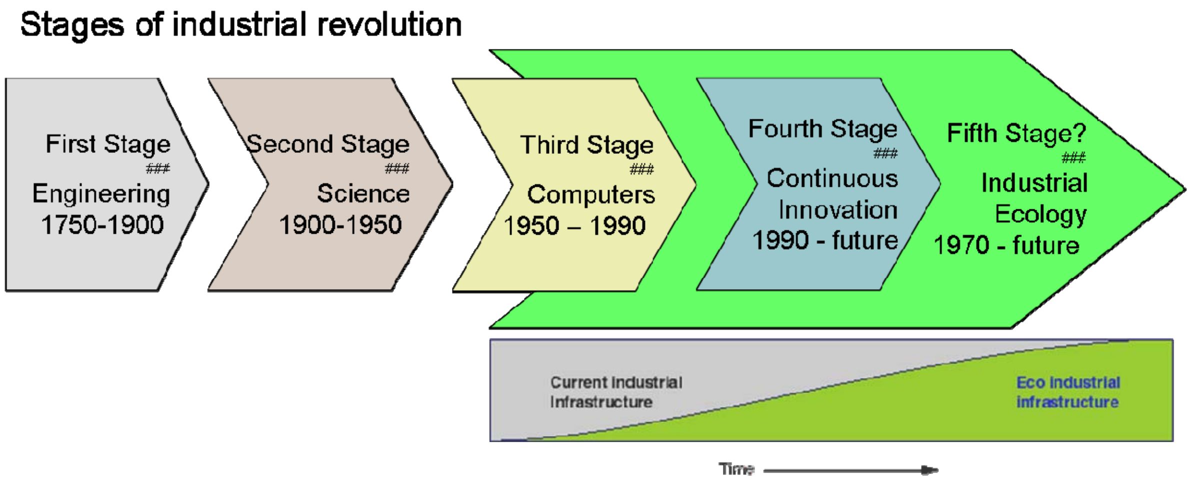

Figure 3-8: Stages of industrial revolution mapped on the progression toward industrial ecology

This then suggests a concurrently maturing stage called ‘industrial ecology’ to track the progress toward an eco-industrial infrastructure. The illustration above also suggests that a significant contribution in the move towards an eco-industrial infrastructure will derive from and rely on technological advances. Four generations of environmental technology have been identified by the International Institute for Sustainable Development. They correspond to the fifth stage of the industrial revolution labelled as Industrial Ecology in Figure 3-8, above. They are briefly summarized in Table 3-1 (Thompson Gow and Associates 1995). The latter two types of technology, pollution prevention and sustainable technologies are the least mature and require increased investment to help society move towards industrial systems that achieve the goals of zero-waste or 100 percent efficiency.

Table 3-1: Four Types of Environmental Technologies

Generation	Point of Application	Characteristics
Remediation – 1970s	address symptoms; clean up damaged resources/environments	- after the fact and costly - range from low tech to high tech
Abatement – 1980s	pollutant capture or treatment at end-of-pipe	- consumes capital, energy and resources; fairly costly - generates waste steam
Pollution Prevention – 1990s	- industrial process design - product design or composition	- reduces or prevents pollution; more cost effective than abatement - reduced waste stream
Sustainable – 2000s	alternate product or service, e.g. organically grown food	multiple benefits: environmental, economic, social; resource efficient

Ehrenfeld (2005) is a strong proponent of increasing the attention given to sustainable technologies as he contends that industrial ecology has focused too long on merely 'reducing unsustainability' rather than addressing the systemic foundations of sustainable development.

It is a premise of this research that industrial parks can be viewed systemically. As a system, an industrial park is a whole composed of parts, with a boundary, and observable inputs and outputs flowing across the boundary and all embedded within the natural systems of the planet (Lowe, et. al. 1997). Haskins (2006) discusses a special case of the industrial park referred to as an eco-industrial park, or eco-park. One observable attribute of the eco-park is that it attempts to 'close the system' by creating symbiotic relationships within the park by which the waste output of one firm is shared as a resource input for a neighbor. The water cascades, and other linkages, in Kalundborg industrial park in Denmark are the most frequently referenced examples of this solution. However, Fiskel (2006) believes that there is so much uncertainty in our understanding of both ecosystems and industrial systems that both should be viewed as "dynamic, open systems that operate far from equilibrium, exhibiting non-linear and sometimes chaotic behavior." (Fiskel 2006: 4)

Industrial parks can be examined from three points of view: 1) micro-levels – firms; 2) meso-levels – parks; and, 3) macro-levels – regional and wider networks (Fet 2002; Roberts 2004). Sustainable industrial parks are more likely to materialize in a 'facilitated' environment (meso-level) where there is the correct mix and structure of willing firms and the correct infrastructure (macro-level) including financial, government and expert advisors at the regional level (Tudor et. al. 2007). These levels can be related to the Hitchins layers (discussed above) – micro-levels correspond to layers 1, 2, and 3; meso-levels to layer 4, and macro-levels to layer 5.

Hitchins (2007) describes 'the organismic analogy' as a basic tenet of systems thinking and systems engineering. According to this view, civilizations and enterprises can be seen to behave like organisms, with conception, birth, and life, followed by collapse, decay and death. Nature's model is the foundational metaphor of Industrial Ecology; the life cycle of an industrial park (or other social community) can be viewed in the same way as the stages of a forest or other natural system or organism. These stages are summarized as Creation, Growth, Development, and Renewal and illustrated in Figure 3-9.

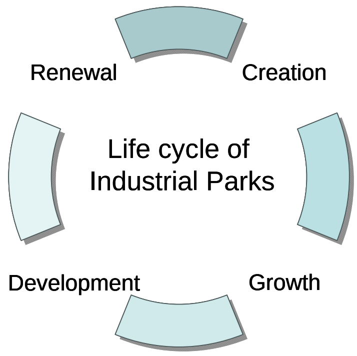

Figure 3-9: The life cycle of a sustainable industrial park

During the creation stage, many ideas are generated; there is an abundance of energy, and a desire to make something happen. It is helpful to create a shared vision of how the community will look in the future during this phase. Trial and error teaches what works, and this learning is applied during the growth stage. The participants begin to understand the role they play in the overall context. The development stage is typified by more maturity, continued growth, and institutionalization of 'what works' such that success breeds success. But success also breeds the conditions that constrain unlimited growth. Eventually, the status quo is threatened by the need for change and renewal begins. In nature, a fire that destroys a section of the forest but allows dormant seeds to burst out into newly-accessible sunlight is an example of this destruction and renewal phase. At the end of a life, every entity experiences a form of creative destruction that eventually leads to renewal and re-creation (Holling and Gunderson 2002).

Were the life cycle not sustainable, the final phase would be something other than renewal, which explains the many abandoned industrial facilities (brownfields) that exist today, waiting for rejuvenation. As an example, the University of Waterloo has launched a research team to apply systems engineering approaches to assist Canadian communities to redevelop their brownfields (Hipel 2006).

No discussion of industrial ecology is complete without mentioning the political and socio-economic context of the technological challenges. The first industrial revolution changed not only the way people lived, but also the foundations of economic thinking; introducing the concept that economic growth is a measure of human well-being. Two hundred years of literature have fed the fallacy that natural and human capital do not have intrinsic value, and that since natural sources are cheap, they must be abundant.

To reverse this trend, whole branches of economics have been derived to deal with the subject of industrial ecology; including Natural Capitalism (Hawken, et. al. 1999) and Environmental Economics (Kolstad 1999). Ecological economics is a recently established transdisciplinary field in which the economy is viewed in a holistic context that includes global legal and social structures (Costanza 1989; Common and Stagl 2005). Achieving the necessary changes in accounting for the environment is equivalent to creating "the next industrial revolution" (Hawken, et. al. 1999: 9).

3.3.2 Achieving sustainable development

Sustainable communities everywhere aspire to be a place where people can raise their children and offer young people enough opportunity to allow them to stay and raise children of their own (Prescott 2003). A Norwegian national evaluation (OECD 2006) found that industrial business parks improved the survival potential of the businesses situated in the parks and serve as gateways between institutions of higher education and the industry in the districts.

Studies conducted by the Confederation of Norwegian Business and Industry (NHO) shows that firms contribute to the fabric of society by engaging in their core business. When they prosper, the whole community prospers through the distribution of wealth via payroll, taxes paid to the state and municipality, interest paid to lenders, goods and services purchased, and dividends paid to shareholders (when applicable). The work they provide generates both income and a sense of self-worth for the individual employee (Lundeby 2007).

In his short article on how planners can benefit from systems thinking, Hauck (2005) offers the following five insights:

- Cause and effect relationships are not always linear; they are frequently delayed in time and unpredictable.
- Many successful systems have evolved through incremental adaptations.
- Many capacity development processes do no have measurable objectives, but are guided by implicit intentions and ideas that adjust to emerging situations.
- Interconnections among the components of a system are important and can give rise to valuable synergies.
- Feedback is critical for learning and self-awareness, but the form it takes is culturally determined and can not be applied in a standardized manner.

These insights are relevant to the creation of indicators and measurements for sustainable development. They coincide with experiences in the UK government's sustainable development program, which seeks to maximize local participation in the selection and continuous monitoring of sustainable development indicators for sustainable communities (Collins 2002).

Hjorth and Bagheri (2007) agree. They use system dynamics modeling as a means of learning about rather than forecasting the implementation of sustainable development in a system under study. Their contention is that traditional planning techniques with 'fixed goals' fail to recognize the process-based nature of sustainable development. Sustainability serves rather as an 'unattainable goal' that motivates firms and governments to continuously strive for perfection.

The primary area of investigation of this thesis concerns those firms and governments striving toward some definition of sustainability. However, while not a primary research focus, it completes the picture to consider the other three quadrants of the sustainable development matrix; namely, those not working toward sustainability. Figure 3-10 contains a context matrix for considering both positive and negative sustainable development.

Social equity concerns occupy the horizontal axis of the sustainable development context matrix; reading from left to right, spanning a lack of social equity to perfect social equity. On the vertical axis is eco-performance, which is defined as a combined view of economic and ecological/environmental practices, following the guideline that attention to the natural environment is 'just good business' (Porter and Kramer 2006). On this scale read from the bottom up to measure increasing positive eco-performance. The upper right quadrant is the area of interest that receives the most attention in the literature. In the lower right quadrant, social equity issues are addressed, but the standard of living is achieved at the expense of the environment. The burning of 'dirty coal' in China and the current rate of rainforest depletion in Brazil are both examples of this category of behavior. An option whereby countries without rainforests pay a 'tax' to these countries to represent their dependence on the existence of the forest is an example of one way that social equity could be preserved and the negative effects of deforestation reversed (Phillips 2006).

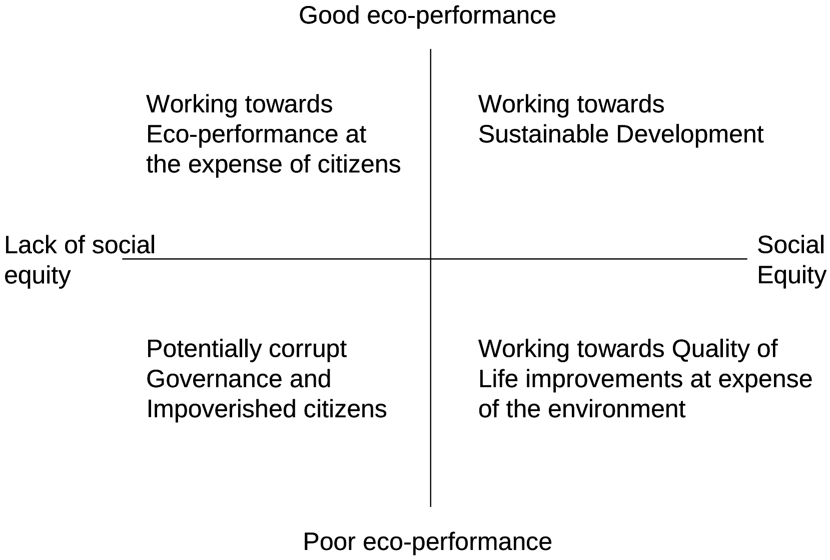

Figure 3-10: The sustainable development context matrix

The opposite set of priorities is found in the upper left quadrant. Here there is attention paid to the natural environment, but the conditions of the people in these regions reflect a lack of global social equity. A country that focuses on technology and enlightened industry but denies its citizens a democratic process or share in the prosperity would be categorized in this way. Concerted efforts to create jobs or subsidize infrastructure services are just two ways that improvements might be made in this quadrant. Fortunately, while there are some, the number of examples of firms or countries whose practices fall in the lower left quadrant is relatively small. World development aid organizations and world relief agencies exist to assist the citizens of these places. This research for this dissertation focused on the upper right hand quadrant labeled ‘Working toward sustainable development’ and is further discussed in section 6.

In summary, to qualify as sustainable, an industrial park must focus at the micro (tenant firms) and meso (industrial estate) levels on the sustainable development triad – equity (in dealing with social issues), economic prosperity (for the company and the community), and stewardship for the natural environment (protecting the legacy of future generations). The principles of sustainability require that attention is paid to economic, environmental and social issues with equal weight.

4. Contributions toward Systems Engineering

4.1 Systems Engineering Methodology

The fact that there are so many models of systems engineering from which to choose is a clear indication of the difficulty practitioners encounter in conveying the principles, processes and related activities of systems engineering. Haskins (2008b) analyzes the source language used to describe the twelve most often cited systems engineering models. This analysis yielded a total of thirty-eight most frequently occurring activities.

The baseline reference for systems engineering is a generic problem-solving process as described by Chase (1974). This is the simplest model, with only eight specified activities, as compared to Evo/Planguage, which covers thirty-six (36) activities. The reference model is old and suffers from the deficiencies pointed out by Checkland and discussed above in section 3.1.2. Planguage, in comparison, requires a steep learning curve to derive value from all activities – although there are start-up techniques for deriving immediate value, and case histories to demonstrate that they work (Gilb 2005).

Visually, the models suffer from another deficiency. With the exception of the spiral and the Plowman model, all the frameworks for which a visual presentation exists, are shown as linear constructions. Agreed, these constructions are filled with a multitude of feedback loops, but these loops only serve to make the graphics look more complicated without dispelling the initial impression of a stepwise, linear progression from beginning to end. Observe Figure 3-2, which is one of the earliest and most popular illustrations of the systems engineering processes; the artist has encased the linear process in an oval to visually reinforce the image of continuous feedback.

To quote Forrester, "We do not live in a unidirectional world in which a problem leads to an action that leads to a solution. Instead, we live in an on-going circular environment. Each action is based on current conditions, such actions affect future conditions, and changed conditions become the basis for later action. There is no beginning or end to the process." (Forrester 1998: 2-3)

To justify the introduction of a new model, it should address the deficiencies of those already in existence. The model must be simple to read and understand, it should avoid 'jargon', it must express circularity, and it must be something that small and medium sized groups and organizations can apply without years of training (Halé 1995). Checkland described the natural aversion to 'jargon' as "… any attempt to use technical terms in describing human activity or social systems." (Checkland 1999: 11) These four criteria may explain the popularity and wide application of the Shewhart (or Deming) cycle, also know as the PDCA (for Plan, Do, Check, and Act) cycle. The PDCA concepts were first introduced by Walter Shewhart in the 1920s, and later adopted and promoted by Deming while consulting with the Japanese (Deming 1986), and are still popular today. Others also have devised simplified systems engineering frameworks, notably Fet (1997) and Mar (Mar and Morais 2002). The latter, called FRAT, is not further discussed because, despite its simplicity, the acronym is composed of jargon and its process engine does not meet the criteria for circularity.

The author proposes a new methodology called **SPADE;** a simplified framework reformulated from the principles of systems engineering. The acronym is constructed from the words Stakeholders, Problem, Alternatives, Decision-making, and Evaluation. Figure 4-1 is the graphical representation of **SPADE**. Note that **SPADE** was first introduced in Haskins (2007) with the acronym iFACE. The original acronym stood for the following phrases: identify stakeholders; frame the problem; develop alternatives, choose a course of action; and, evaluate continuously. It was later decided that a noun-based methodology provided more flexibility for use as a framework for analysis. The methodology is also referred to as a framework to reflect its ability to provide a structure for the analysis of activities.

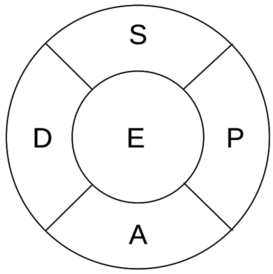

Figure 4-1: SPADE methodology/framework graphical representation

The **SPADE** methodology/framework is a non-linear representation; it can be entered at any point and traversed left or right or even across the center. However, common sense, and empirical evidence suggest that entering the framework by first choosing a solution – such as a governmentally mandated action – before achieving the consensus of stakeholders, or evaluating alternative courses of action, is most likely to fail (Kim 2007). The following sections further define **SPADE** methodology/framework.

4.1.1 Introduction to the SPADE methodology/framework

Stakeholders

According to stakeholder theory, the term stakeholder refers to anyone who is influenced, either directly or indirectly, by the actions of the firm (Mitchell et. al. 1997). The model begins with this step to recognize the critical importance of stakeholders to any human activity. The search for those who influence or are influenced by the system is continuous (Haskins 2008a). Stakeholders must be drawn from all critical sectors – industrial, agricultural, energy, transportation, service providers, government, and citizenry – all needing to work together. Facilitation methods must be capable of eliciting the requirements from farmers, company executives, logistics managers, mayors, and consumers.

Problem

Problem formulation is a never-ending activity to understand the needs of the stakeholders and address conflicting needs; analyze the current situation and hypothesize about alternative futures; establish measures of performance and success criteria to later determine if satisfactory results have been achieved. Systems thinking methods stress the importance of first defining the problem that requires attention. But framing the problem under the conflicting and often equally important set of view-points of diverse stakeholders is not trivial. The important factor in this stage is to collect as many perspectives to the problem as feasible.

The temptation is to stop too soon; to consider the problem framed once the technical product exchanges have been identified or the mayor has agreed to a community park, or feedback has been received from a regulatory agency. Pressure to apply a quick-fix or failure to look systemically at the wholeness of each situation will degrade the eventual outcomes. Partitioning the problem to address it iteratively in subsequent cycles is one way to deal with this complexity, but only after it is understood on a holistic scale. This is a time consuming and continuous process, and the problems will shift with shifting stakeholder involvement, and the changes in the natural and political contextual environments.

Alternatives

The many viewpoints collected during problem formulation will each suggest different approaches to resolving the problem. As the problem continuously shifts with changing situations, so too must the options under consideration be updated continuously. For example, finding alternatives that address the needs of a local community will involve economists, politicians, regulatory agencies, NGO's, technicians, and social scientists. Identifying alternatives is a highly creative process and is the point in the process at which novel ideas and innovations are most welcome.

Decision-making

People influence the quality of decision-making. Choosing a course of action implies a commitment of money and other resources. Some choices are accompanied by the need for cultural changes, which means that addressing the introduction of change is a critical element for choosing a course of action.

Making a decision is not a "once and done" event. Refinements to a course of action should be made continuously to integrate new solutions or activities that work toward resolving the problem and satisfying the stakeholders. Advice about making decisions appears in both the engineering and organizational theory literature.

Evaluation

Evaluation appears in the center of this model for a reason – this activity touches all other activities. Continuous evaluation means being open to recognizing new stakeholders, allowing their late-arriving viewpoints to influence the framing of the problem and the list of alternative options. Decisions are evaluated based upon measures of performance and success criteria identified at the time of problem formulation.

Once stakeholders adopt a solution and make any necessary cultural changes, they begin to act in a new way. Feedback from the stakeholders will suggest possible adaptations that refine and improve the system and shift the process to another step. Since no solution will ever be perfectly satisfactory, or operate in a static, unchanging environment, this cycle continues until the stakeholders decide to stop participating.

Summary

In summary, the **SPADE** methodology/framework incorporates the systems engineering principles of systematic collection of information, constant communications to keep stakeholders informed, and ongoing process development to establish guidelines for how to define the problem, consider alternatives, make a decision that balances the requirements, monitor the resulting situation, and make adjustments as needed – within the context of the current situation. Casual inspection shows that the model meets three of the four criteria; the model is simple to read and understand, it is expressed in straightforward language and it visually expresses circularity. Ease of use of the **SPADE** framework is the topic of section 5.

4.1.2 Comparison to other models

The Fet (1997) six-step systems engineering model is a simplified model derived from Blanchard (1991). The Fet model uses a simple vocabulary that can be readily described and implemented. The criterion for circularity is met by the feedback loop connecting each step to each other step. Fet and Moritz (2004) document one example of the use of the model as a framework for analysis. Figure 4-2 contains a mapping between the Fet six-step systems engineering model and **SPADE**. The mapping is somewhat arbitrary as the activities of step 2 straddle understanding the needs of the stakeholders and framing the problem. Both the Fet six-step process and **SPADE** do not address elements of project management such as negotiation for human resources or project planning, all of which are value-added activities that take place alongside the activities of systems engineering and are sometimes referred to as systems engineering management (Kossiakoff and Sweet 2003) or Enterprise Processes (ISO/IEC 2002).

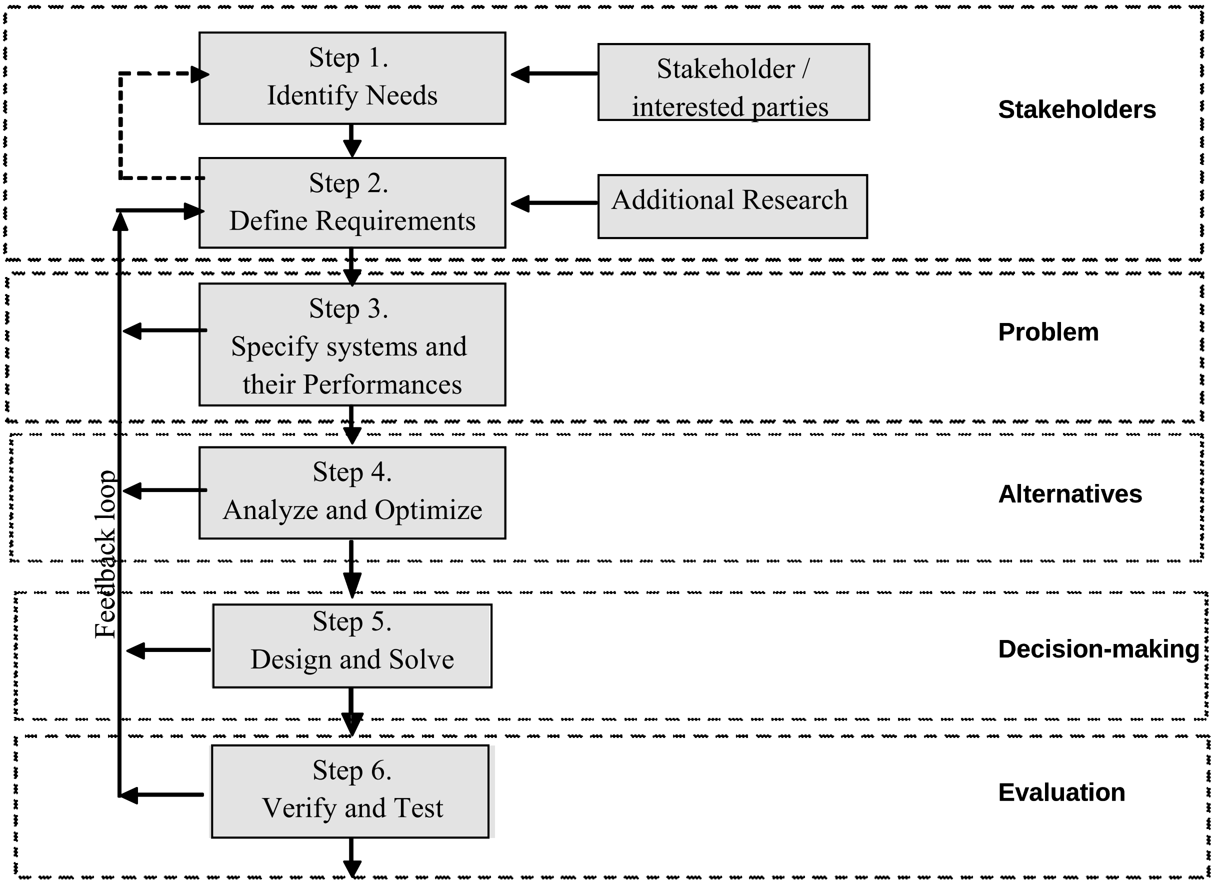

Figure 4-2: Mapping from Fet six-step systems engineering model onto SPADE

The six steps of the Fet model are briefly described and compared to **SPADE**.

Step 1 – Identify needs
The starting point in a systems engineering process is the identification stakeholder needs. Activities described in this step are aligned with Stakeholders in the **SPADE** methodology. Fet (1997) recommends finding the answer to three basic questions. 1) What is needed? 2) Why is it needed? 3) How may the need be satisfied? Answers to these questions provide the input to step 2.

Step 2 – Define requirements
The requirements are the answers to the questions in the first step. Firstly, there are functional requirements that according to Fet (1997) answer the question 'what is needed?' Secondly, there are operational requirements. They reflect the needs of the customer and should answer to question 'why is the system needed?' Lastly, there are requirements that reflect the inter-relationships between subsystems and elements, and how the system fits into the environment (Fet 1997). Activities described in this step overlap Stakeholders and Problem in the **SPADE** methodology.

Step 3 – Specify performances
In the next step, the defined requirements are assigned performance specifications. These are definable and measurable performance criteria for the system as a whole, sometimes allocated onto the parts of the system. This work takes place during Problem formulation in the **SPADE** methodology.

The first three steps in the Fet model are closely linked such that the outcome of the third step is the final quantification of the needs identified in the first step and defined in the second. As suggested by the feedback loop, any of these steps may be iterated as necessary to provide clarifications throughout the entire process.

Step 4 – Analyze and optimize
An essential part of the systems engineering process is a continuous analytical effort. This includes activities for evaluating different system design alternatives by carrying out trade-offs between different, and often conflicting system requirements. These activities take place during Alternative identification in the **SPADE** methodology.

Step 5 – Design and solve
In this step, the preferred alternative is chosen; the solution is designed and implemented. This work takes place within the Decision-making formulation in the **SPADE** methodology.

Step 6 – Verify and test
Before delivering a system, it must be tested to show that the initial needs and requirements are met (as indicated in step 3). In the **SPADE** methodology, this step mostly closely resembles the continuous Evaluation.

4.1.3 Using the SPADE Framework

Systems engineering professionals draw on the tools and methods of general engineering – such as modeling and simulation– plus additional techniques for managing complexity, such as requirements, risk and configuration management (Haskins, 2006b). Although **SPADE** represents a simplification of the superset of systems engineering activities, techniques to facilitate collaboration and participative management must be added to the toolkit, or at least reinforced. The systems engineering toolset needs tools that support the ability of the systems engineer to provide value in situations with multiple stakeholders, seemingly conflicting demands, fuzzy requirements and wicked problems such as presented by complex systems. Table 4-1 contains a list of methods and tools that are useful when applying **SPADE** to a real-world situation. Certain techniques, such as brainstorming and Delphi method, are generally useful and suitable for use throughout the process (Teale, et. al. 2003).

Table 4-1: Methods and tools for applying SPADE

SPADE	**Methods and tools**
Stakeholders	Social network analysis (Breiger 2004; Hanneman and Riddle 2005)
Problem	Concept maps (McCartor et. al. 1999; BeVier and Calimer 2005) Consensus building (Saint and Lawson 1994) Negotiation (Boehm, et. al. 1994) Scenario analysis (Van der Heijden 2005)
Alternatives	Backcasting (Holmberg and Robèrt 2000) Interactive management (Warfield 2006) Specialized trade studies (Hitchins 1992; Buede 1995; 2004).
Decision-making	Decision-making under uncertainty (Buede 1995; 1996) Systemigrams (Boardman and Sauser 2008) Group model building (Vennix 1999)

SPADE	Methods and tools
Evaluation	Key performance indicators (von Geibler, et. al. 2006) Evaluation matrix (Allenby 1996; Blanchard and Fabrycky 1998) Pareto analysis (Smaling and de Weck 2007)

[Note: references in Table 4-1 are non-exhaustive; selected references offer insight into use of each technique.]

By creating the **SPADE** methodology for systems engineering, two things happen. One, the expectation that the systems engineer somehow owns or controls the system is eliminated because the problem is clearly owned by the stakeholders. Two, the stakeholders – business and government leaders, other engineers, citizens of a local community – have a simple framework that helps them apply systems engineering to their problem in an effective way. The extra layers of activity found in most other systems engineering models, such as requirements or risk management, are still useful tools, but they are encapsulated in the value contributed by the systems engineer. This means that the jargon of the many tools and methods found in the systems engineering toolkit, is translated by the systems engineer into the language most appropriate to the audience and the situation.

4.2 The 6Cs meta-model of systems engineering enablement

Haskins (2008b) contains a side-by-side comparison of activities included in the twelve most commonly used systems engineering frameworks. One objective of this analysis was to abstract (or synthesize) the essential attributes of systems engineering. The result is the 6Cs meta-model of systems engineering enablement. The name is derived from the first letter of the six attributes; Communication, Comprehension, Continuity, Collaboration, Cooperation, and, Coordination. Each of the attributes is an equal among equals; it is not more important to communicate than to provide continuity – notwithstanding the intuitive temptation to believe otherwise (Frank 2006; Davidz and Nightingale 2008).

4.2.1 Introduction to the 6Cs of the meta-model

The 6Cs represent common attributes that provide insight into the real work of systems engineering. It is important to remember that the systems engineer is not the owner of either the problem or the solution. The role of the systems engineer is as an enabler, and these attributes, in turn, enable the work of systems engineering – as illustrated in Figure 4-3.

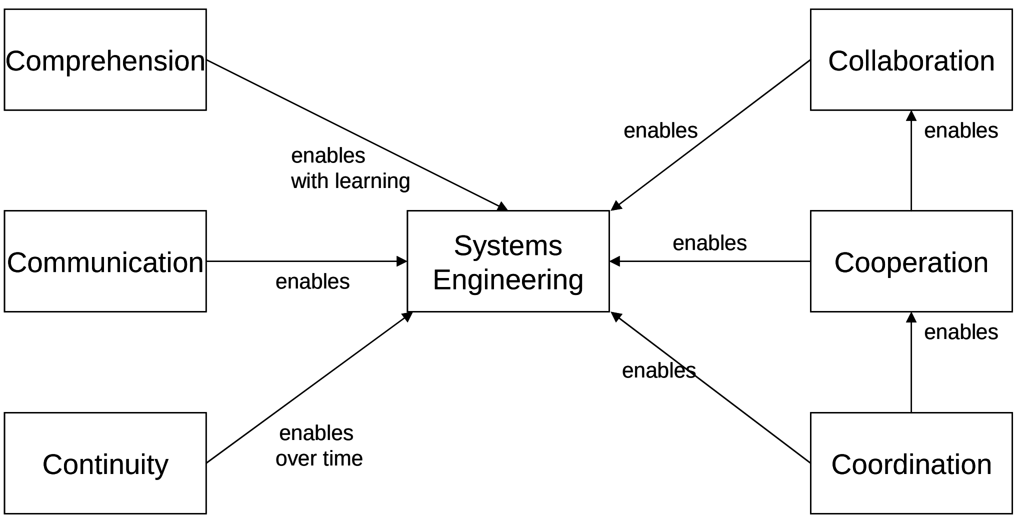

Figure 4-3: 6Cs meta-model of systems engineering enablement

Communication

Systems engineering activities require good communication skills. These skills are essential to avoid the 'Tower of Babel' analogy (Kossiakoff and Sweet 2003). Chase describes this facilitation, "In fact, it must be stressed that a participant in an integrated system design effort… must, therefore, be able to use a commonly understood system-oriented language, and not just his specialist-oriented jargon, which when employed by any number of specialists in relation to a systems-oriented context, can result only in a babel of tongues." (Chase 1974: 21) Sage (2000) refers to this as 'knowledge brokering.'

The significance of communication is recognized in other disciplines. For example, Endres and Rombach observe, "… since system development is more a communication problem than a technical problem. It is more important to think about communication barriers and enablers than about tools that enhance the clerical or intellectual capabilities of the individual." (Endres and Rombach 2003; 82) Try to find a job description today that does not include the catch phrase, 'good oral and written communication skills.'

Including communication as an essential skill is consistent with the findings of the INCOSE working group on the Principles of Systems Engineering (Alessi and McCumber 1998). They concluded that (1) Systems Engineers are responsible for the social consequences of the systems they help create; and (2) the primary products of systems engineering are knowledge and communications. The seminal literature also recognizes the critical role of the systems engineer as a conduit for communications (Hall 1962; Goode and Machol 1957).

Comprehension

Many of the systems engineering activities require the systems engineer to be knowledgeable in a domain, and otherwise able to understand, in a complete way, the information shared by the stakeholders. Jack Ring has stated, "As systems engineers our value is manifested in our ability to comprehend 'the problem' …" (Ring 2002; 19). Chestnut writes, "The approach one uses in solving a problem is greatly influenced by his understanding of it." (Chestnut 1967; 104) Kossiakoff and Sweet (2003) talk of the power of multidisciplinary knowledge, and Banathy (1996) calls social systems design a multidimensional human activity of disciplined inquiry. A systems engineer is a person who listens well, can empathize with underlying value systems, and brings a broad personal knowledgebase to the work of systems engineering. These skills enable the creation of shared visions and common understandings among diverse stakeholders of a problem.

Coordination, Cooperation, Collaboration

The next three characteristics may seem very similar, but each deserves to be included on its own merits. Consider athletic endeavors, such as a soccer game. Each member of the team needs to maintain his/her own balance – or coordination. As an entire group, the team cooperates toward the objective of scoring goals by executing well rehearsed sequences of plays. The game itself requires the presence of two teams, score-keepers and referees, who collaboration according to a well-defined set of rules. The attributes of collaboration, cooperation and coordination build upon each other and form a pyramid of enablement between the stakeholders as they work toward problem resolution, as suggested in Figure 4-3 above.

To use a more business oriented example, consider the use of the home personal computer. Dozens of organizations collaborate across industries to bring electricity into the home. Hundreds of organizations cooperate within the value chain to manufacture and distribute a single personal computer. And, thousands of companies coordinate their software development activities to provide the foundation of applications necessary to make a software operating system successful (Iansiti and Levein 2004).

Coordination

Coordination focuses on a harmonious functioning of parts for effective results. This attribute was recognized by Sheard (1996) as the Coordinator Role of systems engineers. Hall begins his book by stating that "… effective systems engineering calls for careful coordination of process, people and tools. Such coordination cannot be learned from a book or set of books." (Hall 1962; v) Chestnut goes further; "The interplay between the system engineer and engineering design specialist requires the closest coordination …" (Chestnut 1967; 36) The Systems Engineering Handbook agrees that coordination and communication create the biggest challenges for large projects, especially when teams are distributed and can not meet face-to-face (Haskins 2006b).

Cooperation

By cooperation is meant a group of persons working together toward a single defined objective, such as a soccer team, or a project organization. Kossiakoff and Sweet are very clear, "It is the systems engineers who provide the linkages that enable these disparate groups [engineering specialists] to function as a team. The systems engineers accomplish this feat through the power of multidisciplinary knowledge. … Through the ability to understand different languages comes the capability to obtain cooperative effort from people who otherwise would never be able to achieve a common goal." (Kossiakoff and Sweet 2003: 25)

Collaboration

The term collaboration means working together with others, very often people or agencies with which one is not directly connected. This may be especially important when involving the stakeholders in a process. They may have a vested interest, but they exist, most often, outside the boundaries of the defined project team. Likewise, physical systems' interfaces may require two or more separate firms to work together, facilitated by systems engineering oversight. Collaboration is anchored in the pursuit of results (Denise, 1999).

> *Collaboration is not about agreement. It is about creation. …Unlike communications, it is not about exchanging information. It is about using information to create something new. Unlike coordination, collaboration seeks divergent insight and spontaneity, not structural harmony. And unlike cooperation, collaboration thrives on differences and requires the sparks of dissent. (Ibid; 3)*

Continuity

System life cycles and other forms of problem resolution can span a long time. Continuity can be lost unless someone is responsible for that role. Often systems engineers provide continuity. As an example, the Systems Engineering Handbook specifies that systems engineering provides continuity in configuration control and requirements traceability during a project (Haskins, 2006b). For product development, such as automobiles, systems engineers are called upon to continuously upgrade the capabilities of a product to take advantage of technological advances, or to modify components in response to changing legislation regarding safety or pollution control, to name two examples (Kossiakoff and Sweet 2003).

This characteristic is also tightly connected to the need for good decision-making throughout the life cycle. Kossiakoff and Sweet express it this way, "The systems engineer is always the advocate of the total system in any contest with a subordinate objective." (Kossiakoff and

Sweet 2003: 14) According to this viewpoint, the presence of systems engineers in a project enables continuity. In this way, valuable knowledge gained, or networks of collaboration are preserved over time, and valuable time is saved rather than wasted (Tuckman 1965).

4.2.2 Comparison to other models

Vis-à-vis continuity, Hall (1962) discusses the scope of systems engineering in an organizational context, "… only rarely will a particular person, or group, or even a whole organization, follow a system from inception through development, use and obsolescence." (Hall 1962; 11) Table 4-2 maps Hall's objectives of systems engineering from an organization viewpoint onto the 6Cs. Haskins (2008a) contains additional insight into how systems engineers cope with organizational concerns.

Table 4-2: Mapping the 6Cs meta-model on to Hall's objectives of systems engineering

6Cs attribute	Objectives of systems engineering (Hall 1962; 12)
Communication	*Provide management with as much information as possible needed to guide and control the over-all development program.*
Comprehension	*Know the present needs of the organization. Look ahead to anticipate future needs to be fully prepared when the time comes for action.*
Collaboration	*Formulate long-range plans and objectives as a framework for tying together individual projects.*
Cooperation	*Balance the over-all development program to assure progress along all needed lines, at the same time making the best use of development manpower and other resources.*
Coordination	*Develop objectives and plans for individual projects and make these consistent with long-range objectives.*
Continuity	*Keep abreast of new ideas, principles, methods, and devices. Ensure the best and most timely use of new technology.*

In Haskins (2008b) the 6Cs meta-model is mapped onto the superset of thirty-eight systems engineering activities. This mapping indicates that none of the attributes of the 6Cs meta-model is exercised alone. Each activity requires the exercise of two or more of the essential skills of the 6Cs meta-model. A major contribution of this work is that this mapping represents a rare attempt to consider the work of systems engineering in terms of abstract human activity rather than the concrete artifacts of the process or methodology employed (Friedman and Sage 2004).

4.2.3 Using the 6Cs meta-model

In reality, systems engineering has always demanded tact and a natural ability to work well with people. The author next constructed a radar diagram to visually portray the relative need for each of the six attributes for systems of varying 'size' – where size is as yet an unspecified parameter, but small is less complex and uncertain than medium and large encompasses the highest uncertainty and complexity.

Using unspecified size as a parameter, the radar diagram in Figure 4-3 is based on the following assumptions.

- Communication is always important, but a smaller system involves fewer participants and potentially fewer communication transactions.
- The need for Comprehension is the same regardless of the size of system, but one may suppose that a smaller system requires less effort to comprehend. However, comprehension

is most tightly linked to participation with stakeholders, which implies a minimum threshold of effort in every situation and may require more effort than anticipated.

- Coordination, Cooperation and, Collaboration like Communication, are directly proportional to the size of the system under consideration.
- Continuity is dependent on the complexity of the system/product, its lifecycle and purpose; either continuous evolution or highly specialized.

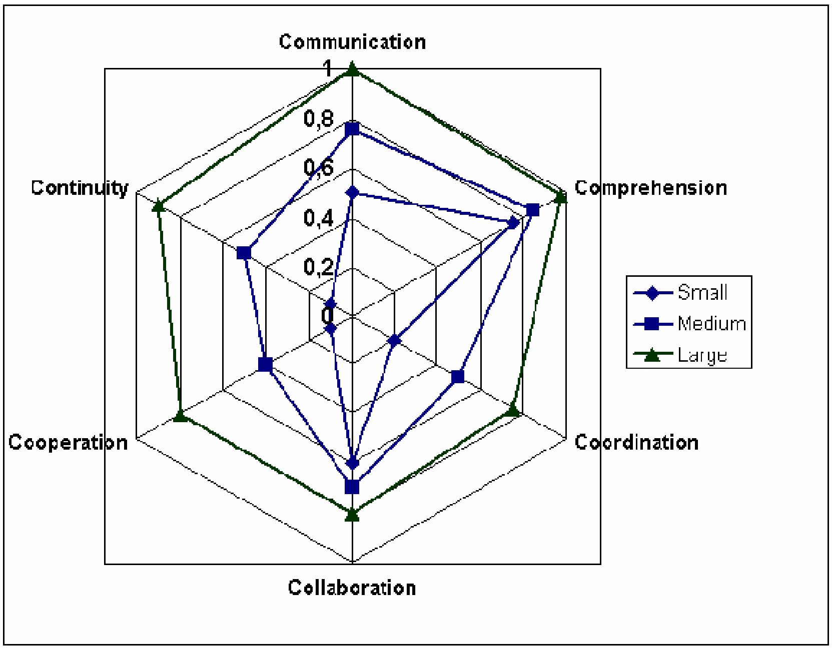

Figure 4-4: Radar diagram of the 6Cs meta-model on systems of varying 'size'

Exceptions to every situation can be found, such as a small system that must wait for an available technology to emerge, and hence requires longer continuity than merely size would suggest. Coordination may be dependent on the effectiveness of the organization itself; well defined and established organizations may require less effort for coordination, even for a large system.

The radar diagram in Figure 4-4 suggests one possible configuration and is the basis for more precise future theoretical and empirical analysis of the 6Cs meta-model of systems engineering enablement.

The purpose for creating a meta-model of systems engineering activities is to address the contention that there are classes of problems to which systems engineering does not apply, and that these include small systems and systems with exclusively social objectives (Checkland 1999). By abstracting the practice of systems engineering to attributes that are readily understandable by people with non-technical skills, systems engineering is opened up to an expanded population for application.

In addition, systems engineering professionals can use the abstract nature of the 6Cs meta-model to learn more about how to exercise each enabling skill. For example, Lozano (2006) uses game theory to support his conclusion that collaborative behaviors deliver a key element for achieving sustainable development. In his analysis, he emphasizes the contributions of all 'players,' including the silent ones such as the environment and future generations of people, plants and animals. Asbjørnsen (1999) agrees that the role of the systems engineer is as the voice of reason, communicating with the public and politicians and serving as the representative of the “fourth party” – the unborn generations to follow, and thus providing a form of ‘forward’ continuity to a project by representing these stakeholders.

4.3 The methodology and meta-model combined

The **SPADE** methodology and the 6Cs meta-model of systems engineering enablement represent the two facets of systems engineering presented in section 3.2.1; namely, systems engineering is both systematic and systemic. **SPADE** provides the user with an organized methodology for addressing problem resolution. A real-world application is discussed in section 5.4. The 6Cs meta-model on the other hand considers the big-picture contribution of systems engineering. The meta-model does not provide any specific guidance about what activities are taken or methods used to achieve the end-result.

The purpose of deriving a meta-model is to explain the relationship of systems engineering activities to each other. The initial relationship identified in this thesis is enablement, as illustrated in Figure 4-3. This means that each element of the 6Cs meta-model enables one or more of each of the superset of thirty-eight activities as well as the activities of the **SPADE** methodology.

The meta-model focuses on the contributions of the systems engineer. Thus, each meta-model element is applied in each of the phases of the **SPADE** methodology depending on the needs of the stakeholders and the real-world situation. This is illustrated in Figure 4-5 and further described in section 5.5.

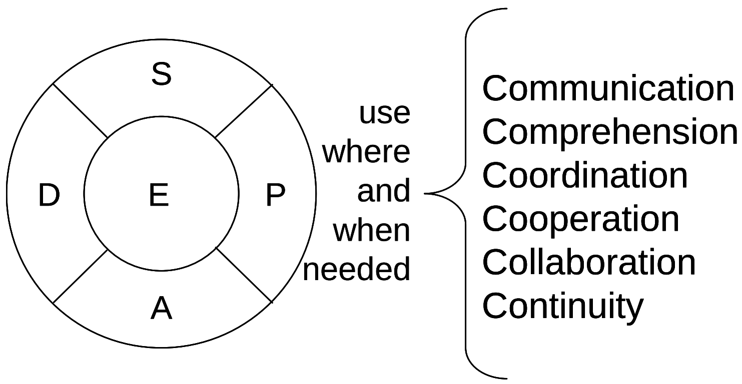

Figure 4-5: SPADE uses elements of the 6Cs meta-model when appropriate

Communication is the one meta-model attribute that is always used in all phases of the **SPADE** methodology. Comprehension and Collaboration are most exercised when working with stakeholders and framing the problem understanding. Continuity includes maintaining good relationships with stakeholders, maintaining the definition of a shared vision, tracking alternatives and evaluating whether they have a history of success or failure to better inform decision-making. Thus, continuity is applicable in all phases, but may not be an important contribution for very short-lived problem resolutions. The abilities to achieve Coordination and Cooperation can also be useful in every phase, but are only exercised when these skills are needed.

5. Verdal Industrial Park Case Study

5.1 Description of the case study project

This work began in December 2006 and concluded in May 2007. The project was conducted in four phases. First, a questionnaire was designed and validated with IndPro management to meet the joint goals of the managers and the researcher. Second, the questionnaire was sent to the CEOs of the tenants of the Verdal Industrial Park (hereafter, VIP) and interviews were conducted to validate the responses. Third, a timeline was constructed from historical archives, and fourth, the responses were analyzed and presented to the VIP community and other stakeholders. A comprehensive final report was written and is available as a working paper from NTNU (Haskins 2007b).

Norwegian census data and other statistics are maintained by the Central Statistics Bureau and are accessible online for analysis. Information about the population changes in the period 1951-2006, and predictions out to 2025, provided an important context to the research that follows. Verdal has had a satisfactory history of cooperation with students invited to study the local firms and the community (Irgens; Kvande; Kvarsvik; Opheim 2002).

5.1.1 Design and validate the questionnaire

It was agreed that adding questions to an annual questionnaire was the best way to reach the CEOs of the VIP tenants who were the target audience for this study. The final set of questions satisfied both the goals of IndPro and areas of research interest. The intention in the design was to use as few questions as possible and to collect information that could serve multiple purposes. Nineteen questions were constructed, and to give them some context, they were categorized as follows:

- Background, Choice of location (Why Verdal?),
- Network profile (relationships within VIP),
- Firm profile (practices related to sustainability), and
- Closing (questions assessing the willingness to participate in a follow-up interview).

A test population was identified to validate the construction of the survey before rolling it out to the entire community. Eight firm CEOs were chosen for their diversity of age and industry and were invited to fill-in the first version of the survey. The initial pilot group were given a presentation and asked to take the survey in the presence of persons who could answer questions. The researcher recorded all questions and suggestions for how the questionnaire and the introductory presentation could be clarified. The length of time needed was also observed to be between 20-30 minutes. Those present were given the option to take the survey online or on paper copies made for this occasion. Five of the eight chose to complete the online survey, which gave a very good indication of how the online survey functioned.

The final version of the questionnaire did not change significantly. Question 13 (regarding inter-firm relationships) was deconstructed from 1 to 5 questions, each able to scroll easily online with the heading labels always present. Some terms were changed to clarify their meaning. After these updates were implemented, the questionnaire was opened to the entire community.

5.1.2 Collect and validate questionnaire responses

The questionnaire was the primary activity of the project around which all other activities were focused. Before launching the questionnaire, a presentation was held for the CEOs to introduce its purpose and goals and to motivate them to participate. The presentation was also used to introduce the concepts of sustainable development as described in Sjöberg (2003).

An online questionnaire design and administration tool, Survey Monkey, was used to manage the invitations and track the responses. Invitations were sent via email and owners of invalid emails were contacted personally over the phone. Reminders were sent out in two week intervals to those who had not yet responded. After one month, non-respondents were contacted by telephone. The final deadline date was extended from mid-February to the end of March before closing the survey.

A representative group was selected based on their willingness to be interviewed and other demographics (Haskins 2007b). The interview questions served the purpose both to clarify results that appeared to be different from the expected responses; and to ask for additional information related to the researcher's area of interest. Interviews with the identified candidates took place in February and April; interviews with other project stakeholders from IndPro and Innherred Vekst were conducted in April. The interviews helped identify any remaining weaknesses in the questionnaire before beginning analysis of the responses.

5.1.3 Construct a historical timeline

The questionnaire responses offer a snapshot of the current situation of the VIP. To put the current situation into context, it was necessary to construct a historical timeline using archival sources and information provided during the interviews.

5.1.4 Analyze and disseminate results

To motivate participation from the busy VIP leaders, they were promised that the results of the survey would be shared with them. It was decided to conduct a seminar that engaged the stakeholders of the VIP, including government officials and planners.

The seminar consisted of a half-day program that began with networking over lunch. The survey results were presented after an introduction from mayor, and the CEO of Aker Verdal and other talks on topics of interest to the audience. The day ended with facilitated brainstorming sessions during which small groups were given the opportunity to debate and discuss the merits of alternative courses of future action, and suggest ways to implement proposed changes (Haskins 2007b).

5.2 Background

The municipality (Kommune) of Verdal is located in a region of Norway known as Innherred, which also includes the neighboring communities of Steinkjer and Levanger. Innherred is located in the county (Fylke) of Nord-Trøndelag. Figure 5-1 presents a map of Norway, with a cutout for Verdal and a photo of the north-most section of the industrial park (artwork from www.innherred-samkommune.no; www.verdalindustripark.no).

The modern industrial history of Verdal Industrial Park starts in 1969, when Aker Kværner opened a factory on the Trondheim fjord (Irgens, 2002; Kvarsvik, 2002). The arrival of Aker was accompanied by fast growth in population and a concurrent housing boom to accommodate the increase from 100 to 1100 employees in only six years (Statistics Norway 2004). When market conditions changed in 1999, Aker Verdal restructured to avoid imminent collapse. This crisis led to 400 persons loosing their jobs and another 500 temporarily laid-off. These job losses exacerbated a depressed job market recovering from a similar situation that had occurred two years previously in Steinkjer, only 30 kilometers north, when a military based closed (Carlsson 2001).

Figure 5-1: Verdal Industrial Park – view from the west

IndPro was formed in 1999 to promote new growth in the area through the acquisition of new tenants for the buildings deserted by Aker Verdal and by finding businesses willing to build on then open land. They established the first industrial incubator in Norway. Beginning in 2000, Aker Verdal began spinning off daughter companies as an alternative to providing all services through internal departments. These new firms settled nearby, and this was the initiation of what is today known as Verdal Industrial Park (Kvarsvik 2002). IndPro/Proneo remains responsible for the continued development of the Verdal Industrial Park today.

Verdal municipality qualified for special financial support from the Norwegian state. This support was used to create and implement new projects during the period 2002-2007. The goal of this development work within Verdal and Levanger was to create a local community with a high standard of living, a lively cultural life and a development-oriented industrial sector. With these objectives, they intended to establish well-paid job opportunities and a strengthening of the industrial base in the municipality (translated from the Innherred Vekst website, www.innherredvekst.no).

The Verdal community has rejuvenated over the past seven years while the supporting industrial based has evolved from a single large firm supported by disjointed service providers to an integrated industrial park (Opheim, 2002). The statistics from the Norwegian Census Bureau show that growth in population and new jobs exhibit large variations that can be linked to fluctuation in the economic health of the area. At this time, 2007-2008, the prognosis is good for steady growth in the region. Thanks in part to governmental funding, the incubator, and the competent guidance provided by IndPro, Verdal is considered the industrial center of the Mid-North Norway geographic area. The transformation has resulted in a strong regional identity (Haskins 2007b).

5.3 Research results

The following sections give a brief summary of the project and research results. For a detailed discussion, see Haskins (2007b).

5.3.1 Questionnaire

One hundred and twenty (120) leaders from VIP firms were invited to participate. Of these fifty-eight (58) responded to the questionnaire, and of those, twenty-nine (29) agreed to be interviewed afterwards. VIP contains firms from a diversity of industries; and, nearly every industry sector was represented in the response population. Figure 5-2 illustrates the industrial profile of participating firms. Note that 32% provide consulting and other services; 21% are from the construction industry; 21% represent light and heavy manufacturing combined; and 11% provide industrial sales.

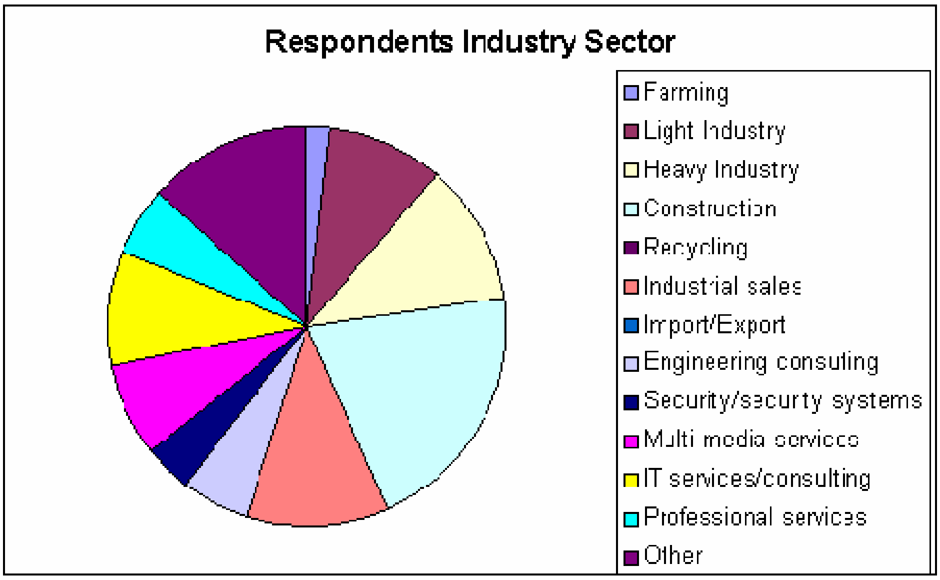

Figure 5-2: Industry sectors represented by survey participation

Financial responses showed that turnover and man-years of effort are closely coupled, although a slight economic down trend is observable in 2002-2003, which corresponds to the initial years of state financial report, meaning some early start-ups were able to operate at a loss. These figures attest to the high productivity of these companies where each employee accounts for a minimum of one million NOK of turnover on average.

Despite examples of partnerships and other cooperation between the tenants of the VIP, the questionnaire results indicate that additional activity should be directed at bringing the existing firms together to enhance their networking, and thereby enable new synergies. Application of social network analysis could be used to further study the existing relationships while helping to recognize potential new relationships within the VIP.

The questionnaire results relevant to sustainable development are discussed in Haskins and Fet (2008).

5.3.2 Interviews

The primary purpose of the interviews was to confirm that the questionnaire had been understood and answered correctly. Although formal questions were written out, most interviews took the form of a conversation about the past, present and future of Verdal – and especially the industrial park. Recurring themes appeared in nearly every interview, and those are summarized in Haskins (2007b) and Haskins and Fet (2008).

A bias in the survey was uncovered during the interviews. The questions regarding proactive action in the firm toward conservation, recycling and operations were constructed in terms that were well aligned with heavy industry and construction, but were not meaningful to the larger proportion of firms answering the survey – see Figure 5-2. This limited the usefulness of this question for drawing conclusions, as is apparent in the discussion in section 6.2.

Another purpose of the interviews was to uncover what the CEOs had learned about sustainable development in Verdal. Figure 5-3 illustrates a shared view of Verdal as a sustainable community with the industrial park as the economic anchor. This shows notable progress as few of the fifteen CEOs interviewed were aware of the term 'sustainable development' prior to the beginning of the survey.

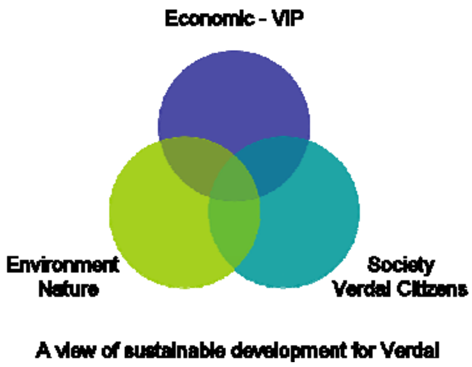

Figure 5-3: A view of the Verdal sustainable community

5.3.3 Timeline

A wealth of original source material was available from which to construct a timeline of activities that occurred in the Verdal community between early 1999 and June 2007. These sources included original Aker Verdal employee newsletters, memos, newspaper clippings from three regional news agencies, the weekly magazine of the national engineering society, and diverse websites (Haskins 2007b). Section 5.4 summarizes and discusses these findings within the **SPADE** framework.

5.3.4 Dissemination and a view of the future

The case study of VIP closed with a seminar that included some reflections from the CEO of Aker Verdal. He feels that he can look back at the events that transpired in 1999 and thereafter with the knowledge that Aker Verdal, as a company, acted in a responsible way. They protected both the future of the firm and the future of local jobs through dramatic layoffs combined with extensive retraining. The firm continues to survive as the cornerstone of the VIP cluster today. But, as he looked at the communication in 2007 about building for the future, he was concerned. He recognizes that the absence of a crisis demands a more open and less dogmatic argument to convince the tenants of VIP that corporate responsibility is good business (Haskins 2007b). He proposed the following vision to take VIP into the future:

> *Norges mest suksessrike industriklynge i 2010 basert på samhandling, felles identitet og bærekraftige innsatsfaktorer! Vision med gjennomslagskraft må ersatte 'fravær av krise.'*

Translation: [VIP shall be] Norway's most successful industrial cluster in 2010 based upon synergy, shared identity and sustainable activities. A vision with the will to follow through must replace 'absence of crisis.'

Plans are already in place to expand the amount of land zoned for industrial use. These plans are being closely coordinated with environmental agencies to preserve the nearby wetlands holding RAMSAR status. The leadership of the VIP has a vision to achieve both national and international recognition as an industrial park with a sustainable environmental profile.

Creating an idealized vision of the future has been recommended as an excellent way to motivate change (Ackoff et. al. 2006; Boroń 2007). Haskins and Fet (2008) report the first thoughts garnered from the brainstorming session. These ideas may be the first germinations of a vision for how the VIP will look in 15-20 years.

5.3.5 Comparison with other cases

When a case study demonstrates a good result, it can be difficult to remember the alternative scenarios that did not materialize. Research on the response of other rural communities to the closure or downsizing of a major employer has recorded a wide variety of consequences that range from few problems and only a mild negative downturn in economic prosperity to much more drastic effects. Some communities have reported crippling downward spirals of lost employment coupled to reduced income and dwindling savings, loss of population in the affected region coupled to a reduction in the tax base, leading in turn to an inability of local government to maintain even basic services and infrastructure.

One study reported on communities in the Midwestern states of the USA that experienced situations similar to that of Verdal (Leistritz and Root 2002). Their report was issued at the end of 2002, but their observations map exactly to the actions taken by the leaders in Verdal. They concluded that communities cope best with the effect of major job loss when the following conditions are in place:

- An economic development organization is in place prior to the closure – this maps to IndPro's formation in October 1999;
- A focus on assisting both displaced workers and economic development – maps to the creation of the incubator and the role of IndPro in encouraging entrepreneurial initiatives;
- Breadth of support from other communities and the state – maps to the state support initiative and other support from within the Innherred region;
- A range of alternative reuse options for the closed facility – maps to the donation by Aker Verdal of their administrative building to house the new incubator;
- An understanding that the adjustment period from downturn to upturn might take months or even years – maps to the multi-year status of state support from 2002-2007.

In short, the actions taken in Verdal created exactly the opportunities and environment for growth that mitigated the potential negative effects of the lost jobs, and resulted in a VIP that is looking forward to continued prosperity through sustainable growth.

5.3.6 Summary

Looking back to 1999, one could describe the changes as a form of creative destruction, which is a normal part of the life cycle of industrial parks – see Figure 3-9 above. In this case, destructive market forces resulted in the creation of the VIP. Today, VIP tenants are making investments in sustainable technology solutions for renewable energy such as windmill technologies and biogas. Start-up companies such as Scan Wind and Ecopro are fully committed to gain a competitive advantage by being first to market with sustainable solutions. Even Aker Verdal is winning contracts in this new domain (Håberg 2007).

5.4 Application of the SPADE framework

This section discusses how the **SPADE** framework, introduced in section 4.1, helps to explain observations of both an established and a start-up industrial park, namely Kalundborg and Verdal, respectively.

5.4.1 Kalundborg, Denmark

The forming of the industrial symbiosis at Kalundborg, in Denmark, is analyzed using the **SPADE** framework in Haskins (2007). Kalundborg is an established industrial park whose tenants were facing steep fines for pollution in the 1970s (Haskins and Fet 2008) and needed to find alternatives to abandoning their plant locations. The solutions they found ensured the continued sustainment and growth of the industrial park (Haskins 2006).

The timeline of the evolution of this metamorphosis from individually polluting industries to clean production through integrated industrial processes corresponds to the fifth industrial revolution as illustrated in Figure 3.8. This eco-park is a favorite example of successful industrial ecology in practice (Desrochers 2001; Jacobsen 2006; Tibbs 1993) and, it is an excellent example of the power of collaboration.

In Kalundborg, the relationship between the firms is highly complementary, with connections at the level of inter-company pipes. Participants deny the existence of any ‘grand plan’ and there was no governmental subsidy. The employees of these firms were looking for innovative ways to reduce the cost of waste treatment and disposal, to find cheaper input materials and energy, and to generate income from their own production by-products (Desrochers 2001). These business relationships have given rise to mutual dependency, relying upon trust and long term personal and professional relationships. When these relationships do not exist naturally, as in Kalundborg, a formal framework, such as **SPADE**, should prove valuable in the sustainment of an industrial park (Haskins 2007). Table 5-1 maps the Kalundborg experience onto the **SPADE** framework based upon an analysis of the literature.

Table 5-1: Kalundborg evolution mapped onto SPADE

S	The stakeholders of the Kalundborg industrial park were initially confined to the industrial tenants; as the symbiosis flourished the municipality and eventually the citizens of the nearby town were incorporated into the system context. These changes have been taking place gradually since the mid 1970’s.
P	Originally framed as a challenge for avoiding paying fines for discharges into Lake Tissø, the symbiosis has expanded into issues of providing clean inexpensive heating to the local community, and attracting new tenants.
A	Many options are considered before each symbiotic relationship is established; those who have documented this progression have insisted that the symbiotic linkage, in each case, presented the best long-term investment for the business partners as the top priority – all other secondary benefits were a bonus.
D	The creation of this industrial symbiosis has taken many years and has been implemented in a series of stepwise didactic connections that have eventually yielded the complicated series of water cascades and other relationships that exist in the park today.
E	Each firm has maintained records that continuously justify the maintenance of the relationships; the Kalundborg Centre for Industrial Symbiosis disseminates ongoing progress reports and information for others who wish to emulate their practices. The industrial park continues to thrive and provide economic benefits to its tenants and the nearby community.

5.4.2 Verdal Industrial Park, Norway

Next, the research turned its attention to the creation of an industrial park. This research, of necessity, was conducted from a near historical perspective (the events were less than ten years in the past). Haskins (2007b) documents the case study conducted in Verdal Industrial Park between December 2006 and May 2007. The study had two objectives; first, the objectives stated by IndPro to conduct a survey of the current tenants, and second, to collect data relevant for the research questions, namely, to examine if **SPADE** provides a useful framework to analyze the creation of the Verdal Industrial Park. The next sections discuss the observations made under each of the framework elements, both historically and during the current project.

Stakeholders

In this case, the point of view taken is that of the entire industrial park, as opposed to a single firm, but the concept applies. The stakeholders of VIP are persons or elements that impact or are impacted by decisions regarding the industrial park. The timeline for the creation of VIP clearly indicates that the buildings donated by Aker Verdal created the impetus to attract other firms to locate their facilities nearby. Geography and strong personal networks were instrumental in identifying the initial stakeholders. Since 2000, the concept of stakeholders for the VIP has grown from employees, potential tenants, the local governmental authorities and institutions of higher learning to include the citizens of the nearby town, tourists visiting the historical Stiklestad battleground, the RAMSAR protected wetlands and nearby bird sanctuary (Haskins 2007b).

Problem framing

In 1999, the problem of imminent and significant job loss was clearly identified. Aker Verdal management framed the problem in this way; since they were creating the situation, they should also take an active role in helping to mitigate its negative effects. They framed the problem as one which they shared with their employees. They established a vision to survive this crisis by laying the groundwork for strong economic growth in the future, and a community more resilient to market changes. The success criteria were that every employee that was laid-off came into a new job and that the municipality should not loose its tax base such that it became unable to provide basic services to the community.

The research project supported IndPro in the collection of data to measure the degree of cooperation already in place between the tenants of the VIP, to measure the amount of import and export done by the businesses in the park, and to create a baseline for mapping future progression toward a sustainable community (Haskins 2007b). Results from this case study will assist in executing future projects. Additional work is needed to establish measures of performance and success criteria for evaluating future projects.

Alternatives and Decision-making

The next two elements of the **SPADE** framework are tightly linked; generate alternative options and make decisions that implement 'solutions' from among the options. In 1999, the management of Aker Verdal faced a number of alternatives for coping with diminishing orders. They could have abandoned the 'non-profitable' Verdal location and let the government provide for the welfare of the redundant employees, or any number of alternative scenarios. Instead, they took a responsible role in ensuring that not only were the employees given the best possible treatment, but the community was buffered from severe economic losses. Rather than demolish buildings evacuated by the diminishing workforce, they donated these buildings for use as housing for the newly established incubator, and other newly formed firms. This action formed the basis for the creation of the industrial park.

The results of these actions can be measured by the fact that within two years every employee was working again and that some of these jobs were created from entrepreneurial initiatives. By 2006, there were more new jobs than the number of employees initially laid off in 2000. The success of these actions is also recorded in the research report that named Verdal the region with the most new start-up firms in the period 2000-2004 (Falstad and Nesgård 2005). The negative scenarios of massive plant closings and other downturns in the USA have been documented in Bradshaw (1999) and present a grim alternative to the positive results achieved in Verdal.

When the case study began in December 2006, IndPro had identified a number of scenarios to address the potential for future growth within the region (Haskins 2007b). They had begun by considering ways to increase the inter-firm relationships within the VIP, to invite in new firms either as suppliers to existing tenants or to expand the diversity of the job-base, to find ways to take better care of the natural environments, and to contribute to the quality of life in the surrounding communities. Before making any decisions, IndPro solicited the stakeholders for alternative actions to take next. The survey and subsequent brainstorming session provide some insight into the vision the VIP tenants see for themselves and the region, and this vision will serve to guide future decisions (Haskins 2007b; Haskins and Fet 2008).

Evaluation

The changes in Verdal that resulted from the handling of the Aker Verdal crisis and the creation of the VIP have been the subject of much evaluation (Irgens; Kvande; Kvarsvik; Opheim 2002). Aker Kværner publishes an annual report on their corporate responsibility performance. In addition, the activity in the period 2000-2002 has been the subject of independent scrutiny (OECD 2006). As recipients of Norwegian funds, annual accounting was made of the progress supported by this financial aid (Verdal Vekst 2002, 2003; Innherred Vekst 2004, 2005).

The timing of the case study coincides with the final year of financial support from the state and the survey contributes to the ongoing evaluation of the status of the VIP. Continuous evaluation has been and will continue to be a part of every IndPro project.

Summary

Table 5-2 summarizes ways in which the activities of Aker Verdal and others led to the creation of the VIP as analyzed with the **SPADE** framework.

Table 5-2: VIP creation mapped onto SPADE

S	The stakeholders of the Aker Verdal crisis were initially identified to include the employees and any educational or governmental agencies that could contribute to retraining or otherwise support the employees as they learned new skills for new jobs.
P	In 1999, the problem was framed as a response to a crisis by creating an environment to stimulate economic growth and emerge stronger and less vulnerable to change.
A	Aker Verdal employees and others were encouraged to bring their new ideas forward for consideration and nurturing.
D	Many projects have been implemented – not all of them with equal success – but the attitude of IndPro, and the hopeful entrepreneurs, is to take risks and try new ideas out in the marketplace. This led to the creation of the VIP to house the start-up ventures.
E	There are many records in the local media, in the academic literature, in the national statistics office, and in corporate reporting sources that document and evaluate the events of 2000-2006. These reports track the social, economic and environmental changes that have taken place in the Verdal municipality.

The next table, Table 5-3, summarizes the ways that the **SPADE** framework is manifested in current and future plans for the sustainment of VIP.

Table 5-3: VIP sustainment mapped onto SPADE

S	As the VIP continues to grow, the municipality, the citizens of the nearby town, visiting tourists, and nearby protected wetlands are incorporated into the system context as stakeholders.
P	To understand their current situation and to envision a future state for the VIP, the leaders are engaging in a series of exercises, such as facilitated brainstorming. Every effort has been made to encourage the participation of as many stakeholders as possible.
A	The idealized vision of the future is being used with backcasting techniques to generate alternative courses of action, which in turn will define future projects.
D	Efficient techniques for evaluating projects and their potential for success have evolved over the past five years and will be applied to select and execute future projects.
E	The intention is to retain contact with NTNU and other independent evaluators.

5.4.3 Experience using SPADE in the case study

The discussion in section 5.4.2 and tables 5-2 and 5-3 has demonstrated use of the **SPADE** framework in the logical sequence of the acronym. However, as indicated in the discussion of Figure 4-1, the framework can be applied in any sequence. In the brief time the researcher was involved the actual course of action was as follows:

- A – IndPro had identified alternative courses of action for consideration
- D – it was decided that a project should be conducted with a survey to gather information about the current situation in the VIP and a meeting to solicit ideas for plans for the future
- E – together, the researcher and IndPro evaluated the questions for inclusion in the survey questionnaire and interviews
- S – it was agreed to limit the survey participation to CEOs of the VIP
- D – the survey was implemented
- E – survey responses were evaluated and documented
- S – during the interviews, the definition of stakeholders was extended to include local educational and governmental representatives
- P – a facilitated brainstorming session was conducted to generate a vision of how to further develop the VIP.

The conduct of this research project is indicative of the real-world modus operandi. It would be too restrictive if the **SPADE** methodology could only be used in the sequence of the acronym. Having said that, consider the first step of the sequence above – although the researcher was presented with a set of alternatives for consideration, the IndPro experts were already very familiar with their stakeholder base, and had formulated the alternatives to address an unarticulated 'problem' of ensuring continued growth in the VIP. Hence, the beginning sequence from their viewpoint was S-P-A-D-E. Since, according to systems engineering principles, it is important to know who the stakeholders are before proceeding to define the needs or problem the use of the **SPADE** methodology encourages good practices for successful projects.

5.5 Application of the 6Cs meta-model of systems engineering

Just like the proverbial question about the tree falling in a forest, one could ask, "Has systems engineering happened if there is no systems engineer in the neighborhood at the time?" The previous section has mapped the occurrences in Verdal in the period 1999-2007 to the **SPADE** framework. How should this be interpreted? One could take the viewpoint of Hitchins (1992) that systems engineering is nothing more than common sense – albeit not very common. Therefore, systems engineering can occur in the absence of professional systems engineers.

In reviewing the case history of the VIP, the role of the systems engineer has been held by two entities; initially, by the management of Aker Verdal, and today, by the staff of IndPro/Proneo. In this role, they exercise all aspects of the 6Cs meta-model of systems engineering enablement, as summarized in Table 5-5.

Table 5-5: Application of the 6Cs meta-model in VIP

Attribute	**Observation**
Communication	Aker Verdal opened lines of communication early in the process and established long-lasting relationships with their employees, local educational institutions, the municipality and the state.
Comprehension	Experience and wisdom have led to a regional vision, which has provided a context for IndPro as they have provided guidance to fledgling entrepreneurs.
Coordination	Shared services are provided in the incubator, including a cafeteria, meeting facilities and office support; these are all coordinated by IndPro.
Cooperation	VIP tenants have a history of cooperating on projects with the help of IndPro.
Collaboration	When zoning changes were needed to expand the VIP, IndPro collaborated with city planners from the municipality and county to smooth the transition.
Continuity	Both Aker Verdal and IndPro have provided continuity during the change processes of the past, and are positioned to continue to provide continuity for the projects of the future.

6. Contribution toward sustainable development

6.1 Monitoring progress toward sustainable development

The literature on the definition of sustainability and appropriate measures or indicators of sustainability is broad and full of debate. Furthermore, recommendations for reporting are more appropriate to larger and multinational corporations (MNC) than to smaller and medium sized enterprises (SME; Haskins and Fet 2008).

Sustainable development at the level of an industrial park can be seen from two, mutually inclusive, perspectives. First, evaluate the overall performance of the area designated as the industrial park – this is equivalent to a 'black box' view of the industrial park as a system. Observe; what raw materials, energy and information flow into the system, and what products, wastes, emissions and discharges flow out. Similarly, the economic inputs and outputs can be measured, as well as indicators for the well-being of the people who move in and out of the system boundary. Second, evaluate the performance of the individual tenants of the industrial park – equivalent to the 'white box' view. Many of the same units of measure will apply, but they will be measured against the individual firms. The latter viewpoint was used during the observations made in the Verdal Industrial Park.

The research questions are focused on the upper right hand quadrant of Figure 3-10 labeled 'Working toward sustainable development.' In order to better define movement through this quadrant it was necessary to understand the nature of the progression of a firm (or any group) toward sustainable development. Since this movement is analogous to learning, or acquiring any other competence, the competence model of learning was used as a framework (Howell 1982). Howell defines learning as moving between the following stages: (1) unconscious incompetence, (2) conscious incompetence, (3) conscious competence, and (4) unconscious competence. This model describes four stages that can be described as a progression from ignorance, to knowledge, then competence, before achieving mastery. Analogies to these four stages of progression have been identified for sustainable development. The stages are named Awareness, Application, Integration, and Leadership.

The stages have been placed into a matrix called the matrix of progress toward sustainable development. This is illustrated in Figure 6-1, against the background of the context matrix for sustainable development, Figure 3-10. Movement along the x-axis reflects increasing maturity in social issues; up the y-axis, maturity in economic and environmental performance. This means that a company with excellent social systems that does not pay attention to their environmental impacts is only assessed as reaching the second stage of commitment to sustainable development – corresponding to application.

An organization can be observed to pass through each of these stages as they increase their commitment to sustainable development. The matrix in Figure 6-1 is constructed such that the social axis is longer than the economic/environmental. One reason for this is to emphasize that all firms with employees have social obligations. It is assumed that all firms must attend to their economic situation to remain in business. However, the degree of environmental impact is highly dependent on the nature of the business of the firm. Firms that provide services versus products will not need to monitor emissions or make investments in cleaner production, for example. This focus on social issues extends into the supply chain, when appropriate. It should be noted that the G3 performance indicators contain more social items than economic or environmental combined – consistent with this view (GRI 2006).

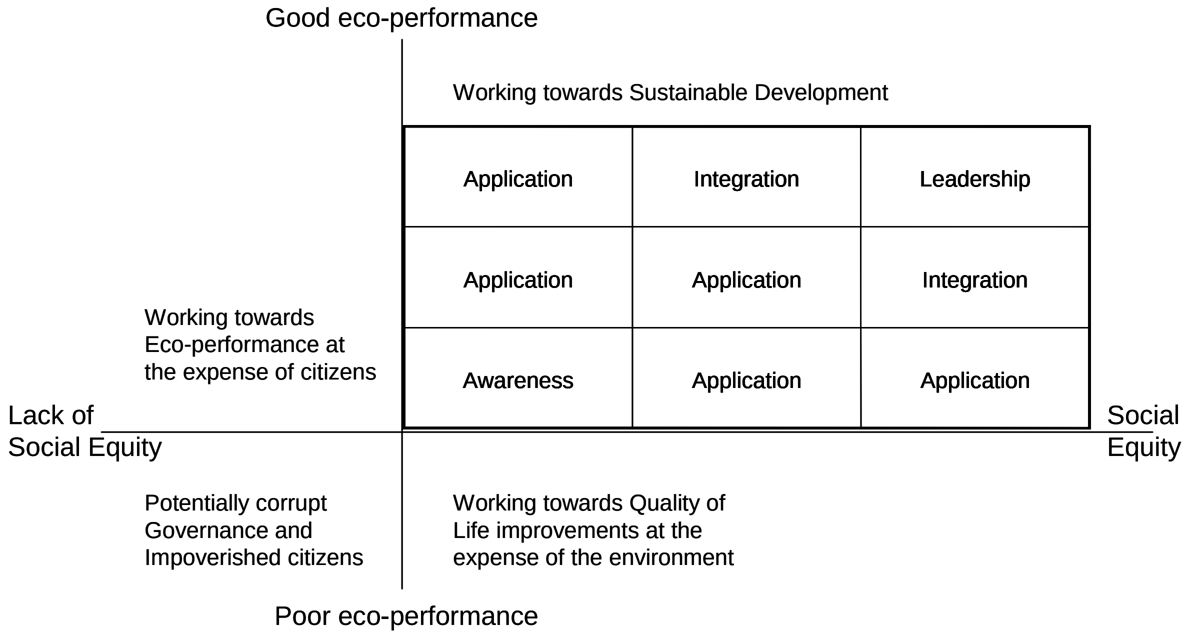

Figure 6-1: Working toward Sustainable Development – individual firm

Table 6-1 provides a definition of each stage and a suggested set of practices that organizations would follow at each stage. These practices are provided as an example and are not all-inclusive. The proposed practices can serve as the basis for establishing and monitoring performance indicators for the organization. Haskins and Fet (2008) contains a discussion of indicators for sustainable development, for example through adoption of an environmental management system (EMS). While not the primary focus of this thesis, it deserves mention that this progression, like any significant change, will take time, and requires a change in cultural values and behavior on the part of every employee in the firm (Leistritz and Root 2002).

6.2 Applying the matrix of progress toward sustainable development to the VIP

This research is interested in determining if any of the tenants of the industrial park practice sustainable development. A very small percentage of the CEOs of the firms in VIP had heard of sustainable development before the project began (Haskins 2007b). Fortunately, the Norwegian Council of Enterprises (NHO) had recently translated a book entitled Sunn Vekst (Healthy Growth) that dealt with the topic of how firms could work toward social responsibility and sustainable development (Sjöberg 2003). Excerpts from this reference provided clear definitions in Norwegian, which were readily understood by CEOs participating in the study. This new awareness made it possible for the CEOs to comprehend and answer the questionnaire and interview questions designed to measure their attitudes and actions toward sustainable development within their own firms. Their answers are analyzed in Haskins (2007b) and, Haskins and Fet (2008).

Table 6-1: Definition of the stages toward sustainable development

Stage and Definition	**Social behavior**	**Eco- behavior**
Awareness Awareness means that the managers acknowledge that the firm has an impact on customers, community, and suppliers and recognize that there are areas where improvements can be made	Open dialogue with employees on hiring, salary and safety conditions	Install energy saving devices; establish and follow-through on recycling initiatives
Application Application is said to happen when the managers begin to take decisions that improve the performance of the firm toward the environment, and regarding the welfare of its employees. Economic performance may also improve as a result of these actions.	Align hiring and salary policies; improve the safety of work conditions; expand concept of stakeholder to include the local community; measure and track emissions	Reduce the use of virgin, non-renewable raw materials; increase recycling; introduce reuse practices; move toward cleaner production; adopt 'green' acquisition practices; conduct life-cycle analysis assessments of environmental impact of products and processes
Integration In this stage, the managers integrate concern for the environment and society with their responsibility to create profit. They create strategy and company-wide programs that achieve objectives in all three areas, and they extend their corporate responsibility into their supply chain.	Strategic planning includes sustainability issues; transparent stakeholder relationships; equitable hiring and salary practices; excellent working conditions; continuous education to maintain and enhance workforce capability; monitor employee satisfaction	Firm adopts EMS reporting practices; attention to environmental impacts extends to the supply chain; invest to redesign product and production methods to achieve best eco-performance
Leadership A company that has consistently performed well and acts as a champion for economic-environmental-social accountability can be seen as a leader and role model for others who would achieve the same goals.	Encourage by example; implement continuous practice improvement; maintain close relationships with local communities	Production approaching zero emissions; proactive raw material replenishment program; investment in research to use alternative materials; participation in industrial symbiosis

The matrix shown in Figure 6-1 was used to conduct an informal self-assessment exercise with the fifteen CEOs who were interviewed. The matrix proved to be easily explained, and easily understood by the interviewees. As expected, not every firm exhibited the same level of maturity in their understanding or practice of sustainable development. Likewise, each firm varied in their own prioritization of the economic, social, and environmental issues. The interviewed CEOs were asked to place an 'x' to mark which phase they thought their company was in right now.

Figure 6-2 is a composite of the self-assessment done by twelve of the fifteen interviewed CEOs. Many needed to be encouraged to give their firms credit for the things they were already doing well (Haskins 2007b). For example, firms compliant with the national labor laws of Norway could assess themselves as at least half-way along the axis for social practices. The researcher agreed with the final placement of the ‘x’ in all cases, but only after learning additional information during the interview. In six of the twelve instances, the researcher had assessed the firm as being in the Application stage, based on the responses provided in the survey.

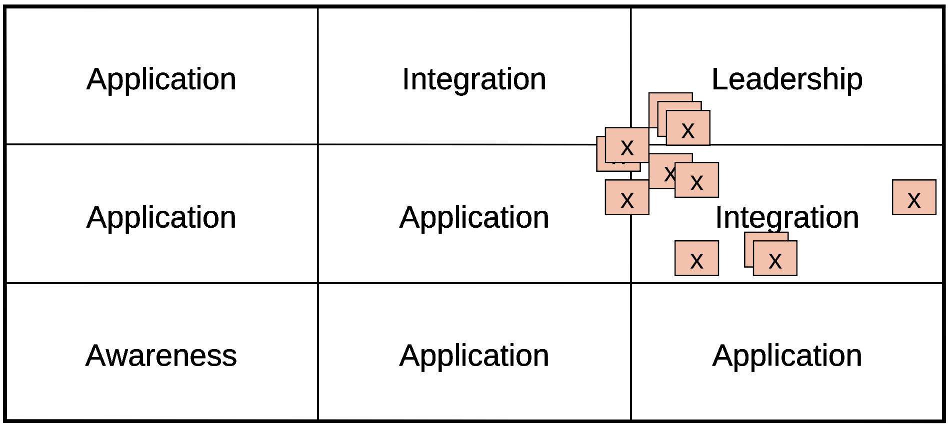

Figure 6-2: Self-assessment by twelve VIP companies using the matrix for progress toward sustainable development – as of June 2007

To provide context for the self-assessment, additional information about the interviewed firms is provided in Table 6-2. As is shown, fifteen CEOs were interviewed. The first column contains a code used by the researcher to track the actual firm and CEO, who otherwise remain anonymous. Column two provides the number of employees as of end-of-year 2006, and a generalized industry sector description. Most of the firms have facilities exclusively in Verdal, although they may conduct business in the region, nationally or even internationally. Two firms are part of larger concerns; another employs subcontractors from outside of Norway; and a fourth uses offshore manufacturing facilities. Column four is the most difficult to present because a reinterpretation of the survey responses was necessary to adjust for the bias against services and consultancies. Only one firm was certified for ISO 14001, although three firms were considering certification. The final column corresponds to the self-assessment; six of the twelve assessments were significantly upgraded based on information gained during the interview. For this reason, the survey responses can only be considered an approximate reflection of the current sustainability status of the respondent firms.

Table 6-2: Stages of progression toward sustainable development in respondent VIP firms – interviewed, self-assessment (with researcher agreement)

N.	N. employees / industry sector	Locale in Verdal	Social / Eco-ranking (survey)	ISO 14001	Self-assessment
P2	40 / construction	Only site	High / High	NR	Integration
P3	4 / services	Only site	High / High	NR	Leadership*
P8	4 / consultancy	Offshore mfg.	High / Medium	Evaluate	Integration
2	270 / construction	Use subcontractors	High / Medium	NR	Integration
3	40 /light industry.	Only site	High / High	Evaluate	Integration
6	50 / consultancy	Only site	High / High	NR	Leadership*
7	2 / services	Only site	High / Medium	NR	Integration*
9	3 / services	Only site	High / High	Unknown	None

N.	N. employees / industry sector	Locale in Verdal	Social / Eco-ranking (survey)	ISO 14001	Self-assessment
10	4 / other	Only site	High / Low	Unknown	Integration*
11	65 / heavy mfg.	Part of larger firm	High / High	Certified	Leadership
13	5 / consultancy	Only site	High / Low	NR	None
16	6 / light industry	Only site	Medium/Medium	NR	Integration*
17	1 / services	Only site	Unanswered	Unknown	None
18	8 / services	Part of larger firm	High / High	Unanswered	Integration*
20	60 / construction	Only site	High / High	Evaluate	Integration

[mfg.-manufacturing] [NR-not relevant]
[* indicates movement from researcher assessment of Application based on interview]

Maignan and Ralston (2002) studied corporate responsibility reporting by firms in Europe and the USA, and concluded that self-presentation served as both an appropriate and useful source of study. However, self-assessment using the matrix is not meant to replace other scientific methods such as material flow analysis, life cycle assessments or other measurement tools whose results are important to informed decision-making regarding sustainable development (Haskins and Fet 2008).

Figure 6-3 presents a view of the progress toward sustainable development in Verdal since 1969 – which predates the VIP. This view is compiled using results collected from online websites of the VIP firms and the case study results. Hypothetical values are chosen for 1969 and 1999, and informally validated by the knowledgeable IndPro personnel who have been around since that time (Seaberg and Krokstad 2007). The values for 2007 are extrapolated from the firm self-assessments and the responses from the VIP survey (Haskins 2007b). An optimistic prognosis about the future of VIP is offered for 2015. The optimism is based on the dedication of the VIP leadership to the goals of sustainable development, the positive attitude of the interviewees, and the nature of the vision for the future that came out of the brainstorming sessions (Haskins and Fet 2008).

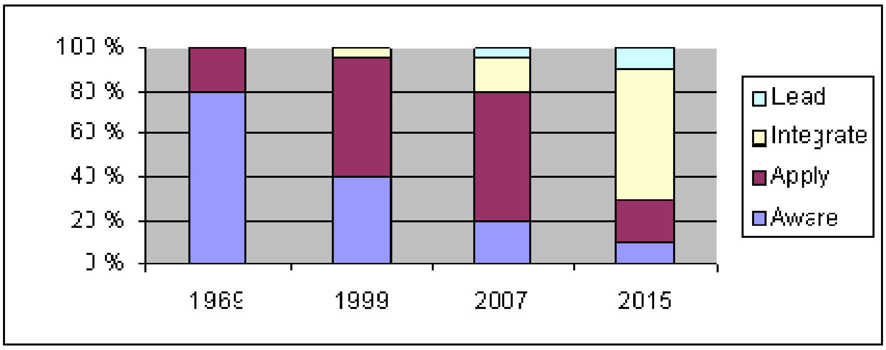

Figure 6-3: Hypothetical progression toward sustainable development in Verdal

Summary of results: Based on the placement of the 'x's in Figure 6-2, one could conclude that firms in VIP are a very good place to work. They are concerned about their employees and follow national directives to ensure a safe and equitable workplace. This means that even the smallest firms in VIP rate very high for their attention to social concerns. Regarding the economic and environmental performance based on this sampling, the respondents feel that they have room for improvement. The environmental profile of the VIP is influenced by the high concentration of firms in the services and consultancy industries. The size of the firms, as reported in Table 6-2, is representative of the fact that the majority of the VIP firms are small or medium sized enterprises.

6.3 Addressing sustainable development challenges for a region

Progression toward sustainable development was previously illustrated in Figure 3-6. Based on this view, as a firm improved their commitment from minimizing pollution to cleaner production to better product design, they move diagonally along the axes toward sustainable development. This point of view can be extended over a longer time span to encompass multiple firms to include an industrial park or a region. Figure 6-4 offers an alternative view of the matrix of progress toward sustainable development to account for the micro-, meso-, and macro-perspectives discussed above in section 3.3.1.

Meso-level Industrial parks	Macro-level Regions	Macro-level Nations
Meso-level Industrial parks	Meso-level Industrial parks	Macro-level Regions
Micro-level companies	Meso-level Industrial parks	Meso-level Industrial parks

Figure 6-4: Working toward Sustainable Development – multiple perspectives

Creating a visual representation of the pathway toward sustainable development is intended to increase the relevance for SME business owners; a simplified matrix and identified stages of progression help the individual business owners to assess their own status while suggesting future activities to help them improve their performance. Leaders at the industrial park and regional levels can use the matrix in Figure 6-4 to plan for progress using a systemic viewpoint. Additional work is necessary to define the nature of these interactions and the specific indicators that are needed. But the pattern of increasing sustainability by moving to the right, and up the scale is consistent with the pattern of the aforementioned figures. And systems engineering has been identified as an enabler of that progression (Fet 1997).

7. Discussion, conclusions and further work

The objective of this thesis is to contribute to the knowledge base of systems engineering and sustainable development; to generate insights about applying the principles of the former to the implementation of the latter. This section discusses the outcomes and contributions.

A recurring theme of the contributions in this thesis has been conceptual simplification – a search for ways to visualize important knowledge such that the uninitiated can understand and use it. The new systems engineering views are intended to put the advantages of systems engineering within the grasp of non-systems engineers. In the same way, the concepts of sustainable development are seen to have the ability to motivate new attitudes toward environmental concern in the VIP (Haskins and Fet 2008).

7.1 New systems engineering methodology and meta-model

The introduction of the **SPADE** methodology and the 6Cs meta-model for systems engineering represent innovations in the dialogue about the practice and application of systems engineering.

First, the analysis described in Haskins (2008b) is the first time that so many of the traditional systems engineering methodologies have been compared side-by-side. Second, criteria for evaluating new systems engineering methodologies have resulted in **SPADE**, introduced in section 4.1, a streamlined methodology that is visually representative of the intrinsically iterative nature of systems engineering and at the same time free of jargon.

Visionaries such as Simon Ramo, John Warfield, and Andrew Sage, just to name a few, have insisted that systems engineering is not only for engineers. It is for 'generalists' (Goode and Machol 1957: 8) who speak the language of multiple domains. For example, Hitchins' five-layer model, shown in Figure 3-5, illustrates this clearly; the languages of industrial engineering and organizational theory are spoken on levels 4 and 5. **SPADE** offers a methodology for applying systems engineering to problems in these levels. Additional case studies are needed to validate the usefulness of this specific methodology, but the usefulness of systems engineering in the domains of value chain and socio-technical systems is established.

The same side-by-side analysis supported the abstraction of six essential attributes of systems engineering, named the 6Cs meta-model of systems engineering enablement, and introduced in section 4.2.

Figure 4-4 shows a radar diagram mapping the relative importance of each of the 6Cs to projects of varying size. This exercise appears to be unprecedented in two ways. First, most presentations of systems engineering activities focus on the artifacts, not on the abilities of the systems engineer. Second, it was not possible to find evidence of any empirical study of the level of systems engineering effort required on a project except at the level of total investment (Honour 2004; Browning and Honour 2008). This diagram is a strawman to initiate the study and debate on which activities are most often performed, and what project criteria have the greatest influence on the level of effort expended, to name two areas of interest.

Section 5 presented the application of both the methodology (used as a framework for analysis) and the meta-model to a real-world case study. The conclusion of the analysis of both Verdal and Kalundborg is that the **SPADE** framework makes the power of the systematic methods of systems engineering accessible to a wider audience of users. The abstract level of the 6Cs meta-model applied to the VIP case, helped to identify that the critical role of the systems engineer was filled by both Aker Verdal and IndPro management. This further validates that 'systemic' systems engineering contributions can be made by persons other than professional systems engineers. However, the value added by the involvement of a professional systems engineer should not be minimized.

7.2 Findings from the empirical research

The selection of an industrial park as the object of the case study has been ironic from the viewpoint of traditional systems engineering. Surrounded by technology industries dealing with a range of products from innovative welding to state-of-the-art theatrical sound systems, the system of interest is none of these. Rather the research focused on the social system of actors and interactions between the tenants of the industrial park. This section summarizes the advantages and limitations experienced in applying the thesis contributions to the case study.

7.2.1 Advantages and limitations of SPADE

Checkland (1999) warns would-be inventors of methodologies about the dangers inherent in imagining that the use of a methodology can itself lead to solutions. The best a methodology can hope to contribute is to help its users to achieve better results by following the guidelines of the methodology than they would otherwise have achieved without it.

The **SPADE** methodology is used as a framework to analyze the events in Verdal between 1999 and 2007. Performing this analysis demonstrates both advantages and limitations of the framework, as summarized in Table 7-1.

Table 7-1: Advantages and Limitations of the SPADE Framework

Advantages	Limitations
Based on systems engineering principles	Projects of a certain sophistication do not benefit from simplification, e.g. aerospace
It can be entered at any point and executed in any direction	It is possible that nothing will happen – this is only negative if there is an option preferable to taking no action
Sophisticated tools and methods are 'hidden' when appropriate	Discussion of the results of sophisticated analysis needs to be directed to the listeners; some project participants will not require or appreciate 'simplified' explanations
Can be used in situations when systems engineering approaches otherwise would not be considered	May be used in situations when more rigorous systems engineering methodologies should be used by professional systems engineers

As Table 7-1 shows, the **SPADE** methodology is not a one-size-fits-all replacement for the richness of models that have evolved throughout the history of systems engineering. However, the results of this research do support the observation that **SPADE** can serve as a mechanism for introducing systems approaches in environments that would otherwise reject the 'heavier' models and methodologies.

7.2.2 Advantages and limitations of the 6Cs meta-model

The purpose of deriving a meta-model is to explain the relationship of systems engineering activities to each other. The initial relationship identified in this thesis is enablement, as illustrated in Figure 4-3. This means that each element of the 6Cs meta-model enables one or more of each of the superset of thirty-eight activities as well as the activities of the **SPADE** methodology. The advantage of the meta-model is that we can speak of systems engineering as an enabling approach for the resolution of socio-technical systems. The limitations are suggested by the concept map in Figure 3-4; namely, the practices of systems engineering are embedded in processes, which must be understood at a lower level of detail.

All meta-models are limited by the high level of abstraction which makes them at the same time useful and useless. On the one hand, is useful to communicate about systems engineering as an enabling activity. This opens up the audience willing to consider using systems engineering. On the other hand, if the only information a user receives is the meta-model, they will not have enough information to actually use systems engineering in a real-world project. The 6Cs meta-model, like all meta-models, must be associated with a methodology.

7.2.3 Advantages and limitations of the matrix of progress toward sustainable development

The literature review did not uncover any clear directions that might prove useful for the SME audience of the VIP (Haskins and Fet 2008). The matrix of progress toward sustainable development, introduced in Figure 6-1, is conceived as a visual mechanism to explain to SME business owners how to improve their sustainable performance; that is improve simultaneously the social, economic and environmental practices of their firm.

An advantage of the matrix is that it is simple enough that twelve of fifteen CEOs who were shown the matrix felt comfortable placing an 'x' to indicate the current position of their firm during their interview, and with some prompting from the researcher. This placement has situational implications. For a service provider or consultant whose primary product is intellectual, their physical footprint is small; even smaller when they share office space with others. They may achieve a status of 'integration' just by recycling and using energy efficient light-bulbs. On the other hand, CEOs of firms in the construction or manufacturing sector have a more complicated situation. They generally employ more people with diverse skills, which complicate their goals for social equity. The products of these firms generally require raw materials and generate wastes and emissions from the production process, all of which complicate their environmental goals. To achieve a status of 'integration' they must pay attention to more factors than the CEO of a consultancy.

This highlights a limitation of the matrix; namely, that the axes do not align with a single unit of measure of performance, and progress is not generalizable, but unique to the company under evaluation. Figure 6-3 proposes a way to aggregate the individual performance of each tenant into a graphical profile of the progress toward sustainable development of an industrial park. Figure 6-4 is offered as an extension to the matrix to encompass regional and even national objectives.

7.3 Further development

In 1999, Verdal was in crisis and people were highly motivated by the instinct to survive, regardless of what framework is used later to explain the results. Ideally, continued use of the **SPADE** framework and the 6Cs meta-model in the Verdal of 2008 and beyond is desirable to confirm or dispute the findings of this thesis. Proactive use of the new methodology in a project would contribute to identifying additional tools for the toolset, for example, tools to help build a community of participation. Equally important is finding other industrial settings, both in Norway and other countries, in which to apply the framework.

The education of systems engineers is challenged by the extensions to systems engineering practices proposed in Haskins (2008b). Haskins (2008a) reports on observations of systems engineering professionals during a workshop, which suggests that additional courses in the humanities and organizational management should be added to the curriculum. The inverse is also true; students of the humanities and management would benefit from more exposure to systems thinking. Educational institutions are increasingly recognizing the value of multi-disciplinary programs, but continuous evaluation is necessary to keep education relevant and to create the next generation of leaders capable of both systemic thinking and systematic activity.

The research agenda for systems engineering is slowly expanding to encompass socio-technical systems. Additional attention is needed in quantifying the value of systems engineering using scales of measure other than monetary investments. The discussion surrounding the introduction of the 6Cs meta-model suggests that additional meta-views of systems engineering activity are waiting to emerge. The initial attempt to evaluate the relative contribution of the enabling abilities across a hypothetical spectrum of projects should receive empirical research attention, as should the question, "Are there other quantifiable metrics that are relevant for valuing systems engineering?"

The research agenda for sustainable development encompasses helping individual firms, industrial estates, regions and nations. Issues of scale and quantification are still unresolved for the matrix of progress toward sustainable development both for the single firm and for larger networks. If the matrix will realize its potential, additional work is needed to identify indicators and other measures of performance.

As stated in the preface, the journey has just begun.

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Appendix 1: Abbreviations, acronyms and glossary

6Cs	Communication, Comprehension, Collaboration, Cooperation, Coordination and Continuity systems engineering meta-model
ANSI/EIA-632	American National Standards Institute/Electronic Industries Alliance 632: *Processes for Engineering a System*
Eco-park	Shortened from Eco-Industrial Parks
EIA/IS 623	Electronic Industries Alliance/Interim Standard 632: *Processes for Engineering a System* (1994, issued to replace Mil-Std 499B)
EMS	Environmental Management Systems
IEC	International Engineering Consortium
IEEE 1220	Institute of Electrical and Electronics Engineers 1220: *Standard For Application and Management of the Systems Engineering Process*
iFACE	The original introduction of the SPADE methodology was published using this acronym – Identify stakeholders; Frame the problem; develop Alternatives, Choose a course of action; and Evaluate continuously.
INCOSE	International Council on Systems Engineering
IndPro	Industry and Product Development (Industri- og Productutvikling); known since July 2007 by their new name, Proneo (not an acronym)
ISO	International Standards Organization
ISO/IEC 15288	ISO/IEC 15288: 2002(E) – *Systems Engineering – System lifecycle processes*
Mil-Std 499	Military Standard 499: *Systems Engineering* (USA Department of Defence)
MNC	Multi-national corporation
NGO	Non-governmental organization
NOK	Norwegian Krone – currency of Norway
NTNU	The Norwegian University of Science and Technology, Trondheim, NO
PDCA	Plan-Do-Check-Act; aka. the Shewhart cycle or Deming cycle/wheel
RAMSAR	UN Treaty for the protection of wetlands
SEBOK	Systems Engineering Body of Knowledge
SEH	The INCOSE Systems Engineering Handbook
SME	Small and medium size enterprises
SPADE	Stakeholders-Problem-Alternatives-Decision-making-Evaluation Methodology
VIP	Verdal Industrial Park

Appendix 2: Papers

A. Multidisciplinary investigation of eco-industrial parks

B. A systems engineering framework for eco-industrial park formation

C. Using patterns to transition systems engineering from a technological to social context

D. Using systems engineering to address socio-technical global challenges

E. Using the concept of sustainable development to encourage corporate social responsibility in industrial park tenants

Paper A.
Multidisciplinary investigation of eco-industrial parks

Is not included due to copyright

Paper B.

A systems engineering framework for eco-industrial park formation

Is not included due to copyright

Paper C.

Using patterns to transition systems engineering from a technological to social context

Is not included due to copyright

Paper D.

Using systems engineering to address socio-technical global challenges

Using systems engineering to address socio-technical global challenges

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Abstract

The discipline of systems engineering continues to mature, but no systems engineer has ever been awarded the Nobel Peace Prize, while economists, politicians and others are putting more attention to the global socio-technical challenges that face the planet today. This paper will explore the essence of the systems engineering discipline and suggest ways in which systems engineering practitioners, researchers and educators can meet the global challenges.

Introduction

The past four Nobel Peace Prize winners have received their award based on contributions to some of the global challenges facing the planet; housing, financial equity, and climate change. Equally remarkable is the long history of esteemed systems thinkers who have espoused the application of various systems approaches to address the global socio-technical challenges that man has created for himself. The list includes Simon Ramo,[1] Andrew Sage,[2] Jay Forrester,[3] Bela Banathy,[4] and Buckminster Fuller,[5] to name a few. Peter Senge (1994) popularised the term 'systems thinking' by earmarking it as the Fifth Discipline that an organization needs to embrace for survival. But in spite of the best efforts of these visionaries, there is insufficient evidence that governmental or business decision-makers consciously use systems approaches in making decisions, notwithstanding that the majority of these decisions involve solutions that address both social and technological concerns.

Those of us in the systems engineering community should be dissatisfied with the negative byproducts of the world created by systems engineers – industrial pollution, traffic congestion on the land and in the air, imbalances in global lifestyle, to name a few. If systems engineers are to remain relevant in the 21st Century, the solutions for these issues can not be relegated to the realms of other disciplines alone. Systems engineers must build both their 'box' (read technology) and the (social) systems that provide a context for the box.[6]

This paper begins with a critical assessment of systems engineering as a discipline. A backward look at the variety of system engineering frameworks and perspectives is analysed to find their strongest common attributes. An overview of cases where systems approaches have been applied to real-world (social or socio-technical) solutions is then presented followed by a discussion of the implications for the application of systems engineering. The paper concludes with suggestions for future research and adjustments in educational content.

Systems Engineering – the discipline

Systems engineering exists as both a process and a method (Kossiakoff and Sweet, 2003). Checkland (1999) offers an extensive discussion of the philosophical and practical roots of systems engineering. Much has changed since Martin's (2000b) evaluation of the scope of the systems engineering profession. The practices have matured into a body of literature that supports a body of knowledge, an organization dedicated to the dissemination of this body of knowledge, and an increasing number of schools and universities offering certificates and degrees in systems engineering at every level.

This paper will not repeat again the myriad definitions for systems or engineering. Suffice it to say, the earliest mention of systems engineering in the title of a book is Goode and Machol's '*System Engineering: An Introduction to the Design of Large-Scale Systems*' from 1957. As is typical of engineering, systems engineering had already been practiced by Bell Laboratories and others for more than a decade (Hall, 1962).

The term discipline derives from the Latin d*isciplina*[7], which were written instructions to pupils or disciples. The term is also associated with methods of training such as military drills. Within educational institutions, the term refers to a formal branch of learning, often associated with a school or department, such as a school of Medicine or a department of Mathematics. Liles et. al, (1995) distilled six basic characteristics that define a *discipline*:

1. a focus of study,
2. a world view or paradigm,
3. a set of reference disciplines used to establish the discipline,
4. principles and practices associated with the discipline,
5. an active research or theory development agenda, and
6. the deployment of education and promotion of professionalism.

These are discussed briefly in turn.

Systems Engineering Focus of Study. The discipline of engineering emerged from man's need to create tools. The basic role of the engineer is to take scientific theory and put it to practical use. Hence, a new engineering discipline must have a unique focus which addresses a human need. Systems engineering, is described as "an interdisciplinary approach and means to enable the realization of successful systems."[8]

This definition is provided by the International Council on Systems Engineering (INCOSE) and further elaborates the need to consider multiple dimensions of the problem in the areas of cost, schedule and performance, manufacturing and test, training and support, and disposal. The objective of systems engineering is to integrate all the contributing disciplines to create a systematic process that proceeds from concept to production to operation, and on to retirement or recycling. The desired end result is a quality system that meets the needs of all stakeholders.

This fundamental definition has led to the development of a body of knowledge, principles, and practices having to do with all phases of the system life cycle. Systems engineering appears to have a unique, if multidisciplinary, focus of study.

Systems Engineering World View. A discipline includes a world view or paradigm that defines the framework for further development of the discipline through practice and research.

Systems engineering adopts the world view of general systems theory in viewing all systems as 'wholes' that can not be properly designed as a collection of parts. This holistic view drives advances in both practice and research relevant to systems of systems[9] - one of the newest topics in the field at this writing. Systems engineering as a profession was motivated by the increasing complexity of man-made systems and uncertainty about their environment (Ferris, 2007). This has led to a basic viewpoint of systems engineering as the balance between "risk-taking and risk-mitigation." (Kossiakoff and Sweet, 2003, 15)

Systems Engineering Reference Disciplines. As a multidisciplinary field of focus, systems engineering, by definition, builds upon a large body of existing disciplines as the base for educating future systems engineers. Given the broad scope of the system life cycle, systems engineering is firmly rooted in organizational theory, economics, mechanical and electrical engineering, to name a few. Recently attention has been given to behavioural sciences to provide a better understanding of human needs and communication mechanisms.

Systems Engineering Principles and Practices. As an offshoot of engineering, systems engineering began as a loose collection of practices that were eventually written down, analysed and refined into a set of principles. Han (2004) analysed and compared nine lists of systems engineering principles found in various publications.

Principles. The principles that apply to systems engineering are often embedded with other disciplines. By way of example, a principle of software systems engineering is “What applies to small systems does not apply to large ones.” (Endres and Rombach, 2003; 71) This principle essentially warns against trying to apply the practices that work in small systems to larger, more complex systems because of issues of scalability; methods that apply to craftsmen do not support industrialization.

Systems engineers should also be familiar with the ‘laws’ from cybernetics and general systems theory relevant to complex systems – a sampling is listed here (with initiating author) without further discussion:

- Requisite Variety (Ashby)
- Requisite Parsimony (Miller)
- Requisite Saliency (Boulding)
- Meaning and Wisdom (Pierce)
- Authenticity and Autonomy (Tsivacou)
- Unintended Consequences (Merton)

Practices are embedded in the variety of frameworks or process models that exist to define the systematic approach to “bringing a system into being”[10] that is espoused by systems engineering. Table 1 summarizes twelve of the most often cited systems engineering frameworks. As the distribution of checkmarks indicates, there is a great deal of consistency between these models, indicating a general consensus on the set of practices appropriate to systems engineering. It should be noted that an unchecked process in the table does not mean the author of the framework is not concerned about this activity, only that the activity is not specified in the model description. The reference model is based on the scientific method for problem solving. Table 2 contains a brief description of each of the frameworks and the source used to derive the comparison.

Table 1 - One dozen Systems Engineering Frameworks

Activity	Ref.	#1	#2	#3	#4	#5	#6	#7	#8	#9	10	11	12
1. Identify stakeholders		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
2. Formulate the problem							✔	✔			✔	✔	
3. Define requirements	x	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
4. Investigate alternatives		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
5. Define performance	x	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
6. Requirements Analysis		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
7. Model the system		✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	
8. Define functions	x	✔	✔		✔	✔	✔	✔	✔	✔	✔	✔	✔
9. Engineering design	x	✔		✔	✔		✔	✔	✔	✔	✔	✔	✔
10. Design Architecture		✔	✔	✔	✔	✔	✔	✔			✔		✔
11. Assess and manage risk		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔		✔
12. Implementation		✔				✔	✔	✔	✔	✔	✔		✔
13. Manage interfaces		✔			✔		✔	✔		✔	✔		✔
14. Integration		✔	✔	✔	✔		✔	✔	✔	✔	✔	✔	✔
15. Define tests	x	✔	✔	✔	✔		✔	✔	✔	✔	✔		✔
16. Verification	x		✔	✔	✔	✔	✔	✔	✔	✔	✔		✔
17. User Training				✔				✔			✔		✔
18. Production support	x				✔		✔	✔	✔		✔		✔
19. Transition				✔		✔		✔	✔		✔		✔
20. Validation		✔		✔	✔	✔	✔	✔		✔	✔	✔	✔
21. Operational support				✔	✔	✔	✔	✔	✔				✔
22. Maintenance				✔	✔			✔	✔		✔		✔
23. Replacement, upgrade											✔		
24. Retirement, disposal				✔					✔				✔
25. Manage baselines		✔	✔	✔	✔		✔	✔	✔	✔	✔		✔
26. Manage project*		✔	✔	✔	✔	✔	✔	✔	✔		✔	✔	✔
27. Conduct reviews		✔	✔		✔		✔	✔	✔	✔	✔		✔
28. Maintain documentation			✔				✔	✔			✔		
29. Manage information	x	✔	✔		✔				✔		✔		✔
30. Address legacy systems			✔					✔			✔		
31. Manage complexity			✔		✔		✔	✔			✔		
32. Capture business plans				✔	✔		✔	✔			✔		✔
33. Manage quality				✔	✔		✔	✔			✔		✔
34. Integrate disciplines				✔	✔		✔		✔		✔	✔	✔
35. Acquisition						✔	✔	✔	✔		✔		✔
36. Supply						✔	✔		✔		✔		✔
37. Continuously re-evaluate		✔							✔		✔		✔
38. Environmental impact							✔				✔	✔	
Total number of checked activities	8	20	19	23	26	17	30	31	26	17	36	14	31

*Details concerning project management activities are suppressed.

Table 2 – key to frameworks described in Table 1

#	Name	Characteristics
	Reference	Based on the scientific problem solving process – mapping provided by (Chase, 1974)
1	SIMILAR	Parallel and iterative processes with re-evaluation to modify the system, the inputs, the product, or the process; purports to contain all elements of other models; based on functional analysis and a definable problem; requires extensive communication and coordination. (Bahill and Gissing, 1998)
2	Plowman	Cyclic and recursive model that is applied at different levels of rigor depending on the type of program or project involved; based on functional analysis and a definable problem; processes linked to standard military documentation artefacts; enhancing communication and system understanding. (Plowman, 2002)
3	Tufts	This model defines eight high-level activities that span from the front end marketing and business capture to operations and maintenance portion of the life cycle; linear and concurrent processes defined; based on CMMi and EIA 632. (Tufts, 2002)
4	Vee	The basis of models used by the USAF and NASA (Forsberg, Mooz, Cotterman, 2005).
5	INCOSE1	Model based on the EIA/IS 632 systems engineering standard; based on functional analysis; iterative processes; “effectively communicate a "shared vision" of the systems being developed and avoidance of omissions or confusion that often result from a lack of integration.” (INCOSE SE Handbook, 2002, pp. 30-31)
6	AT&T	Part of a Process-Methods-Tools-Environment paradigm; extracted best current practice within AT&T. (Martin, 1997; Hall, 1962)
7	GERDC	Early synthesis of diverse practices; functional structure. (Chestnut, 1967)
8	SELC1	Comprehensive model; physical systems; focus on bringing a system into being. (Blanchard and Fabrycky, 1981)
9	Spiral	Risk-driven process for product or system development; iterative. (Boehm, 1986)
10	Planguage	Incremental deliveries provide constant feedback and control risk. (Gilb, 1988, and 2005)
11	NTNU	Linear model, with an iterative problem solving process; focus on bringing the system into being while recognizing useful life and disposal events. SE as a generic process for systematic problem solving. (Asbjørnsen, 1992) Additional modifications were made by Fet (1998).
12	INCOSE2	System lifecycle processes based on the standard ISO/IEC 15288 – Systems engineering – system lifecycle processes. (INCOSE SE Handbook, 2006)

Systems Engineering Research Agenda. The research agenda for systems engineering is as broad as the disciplines that contribute to its definition. Sahraoui, Buede and Sage (2004) proposed a set of issues essential to the growth and application of systems engineering. The Systems Engineering Vision (INCOSE, 2007) contains a list of topics considered critical to the advancement of the profession and the relevance of systems engineering to solving the problems of the future. These topics can be grouped into four primary areas:

- Insertion of systems engineering principles into an expanded curriculum
- Influence of systems engineering techniques in a technical society
- Innovative approaches toward systems engineering education delivery
- Increased collaboration between educational institutions, societies interested in systems engineering, and persons with interdisciplinary interests.

The Systems Engineering Advancement Research Initiative at MIT states, “In order to be effective research must be performed and then transitioned to practice which relates to the realm of complex systems with expanded system of systems scope, complex context requiring a socio-technical approach, and methods to take a value-driven perspective where value propositions involve synthesis of many stakeholder needs.”[11]

In comparison, The Systems Engineering Doctorate Centre at Loughborough University[12] lists their research agenda, developed with industry partners, to address current and future challenges in systems engineering associated with exploiting systems of systems, managing systems complexity, maximising system performance, capacity and capability of affordable systems, and understanding humans in the system.

The four lists indicate agreement about the new challenges facing the profession, and where research can increase the body of knowledge while enhancing the practice of systems engineering.

Systems Engineering Education and Professionalism. In 1990 a group of educators and leaders in the profession of systems engineering met to discuss the future. The result was the formation of INCOSE, and the subsequent growth of the organization to over 7000 members from six continents, representing practitioners, educators and researchers. In 2004, INCOSE established a certification for systems engineering professionals (CSEP) and over 150 people have been certified to-date. Recognition of the value added by systems engineers has been slow, but recently governmental bodies in both the Netherlands and Norway have established investments in systems engineering. In Norway, the Norwegian Center of Expertise in Systems Engineering is established with committed funding from the state for the next ten years to enhance the competitive advantage of this cluster of firms through the use of systems engineering.

INCOSE tracks the programs offering degrees or courses on systems engineering worldwide on their website.[13] The reporting is voluntary and the list is continuously updated. At this writing there were 63 institutions reported in the USA, eleven in China, seven in the UK, six in Canada, two each in Australia and France, and one each in Germany, India, Israel, the Netherlands, Korea, Saudi Arabia, Singapore, and Turkey.

Systems engineering curricula are typified by combined technical depth and breadth in the course of study. Within the USA, efforts are underway to achieve recognition for a systems engineering course of study from the Accreditation Board for Engineering and Technology.

Sage (2000) has also looked at the question of the future directions for systems engineering education. He recommends and expanded curriculum that includes

- team skills, and collaborative, active learning;
- communication skills;
- a systems perspective;
- an understanding and appreciation of diversity; different cultures, business practices;
- integration of knowledge throughout the curriculum a multidisciplinary perspective;
- commitment to quality, timeliness, continuous improvement;
- undergraduate research and engineering work experience;
- understanding of social, economic, and environmental impact of engineering decisions;
- ethics.

“Each of these is particularly important for engineering education, and especially for systems engineering education. This is especially so in light of relevant works that examine the role of technology and values in contemporary society and which stress the need for engineering to become more integrated with societal and humanistic concerns, such as to enable engineers to better cope with issues and questions of economic growth and development, and sustainability and the environment.” (Ibid; 171)

This means that there is a lot to learn, and as multi-disciplinarians, systems engineers need more than ever to be generalists who understand underlying principles without being able to solve a given problem alone (Goode and Machol, 1957). This has serious implications for educational institutions. For example, NTNU is looking into the establishment of a 5 year Master's level degree program in 'systems engineering' to give the student a chance to assimilate a broad range of learning. This activity is still in early investigation stages, but hints at an approach that may alleviate the time constraints.

Summary. Given this discussion of the criteria for a discipline and the corresponding attributes of systems engineering across academia and industry, it should be safe to conclude that systems engineering can correctly be referred to as a discipline. Figure 1 replicates the Biglan classification of educational disciplines.[14]

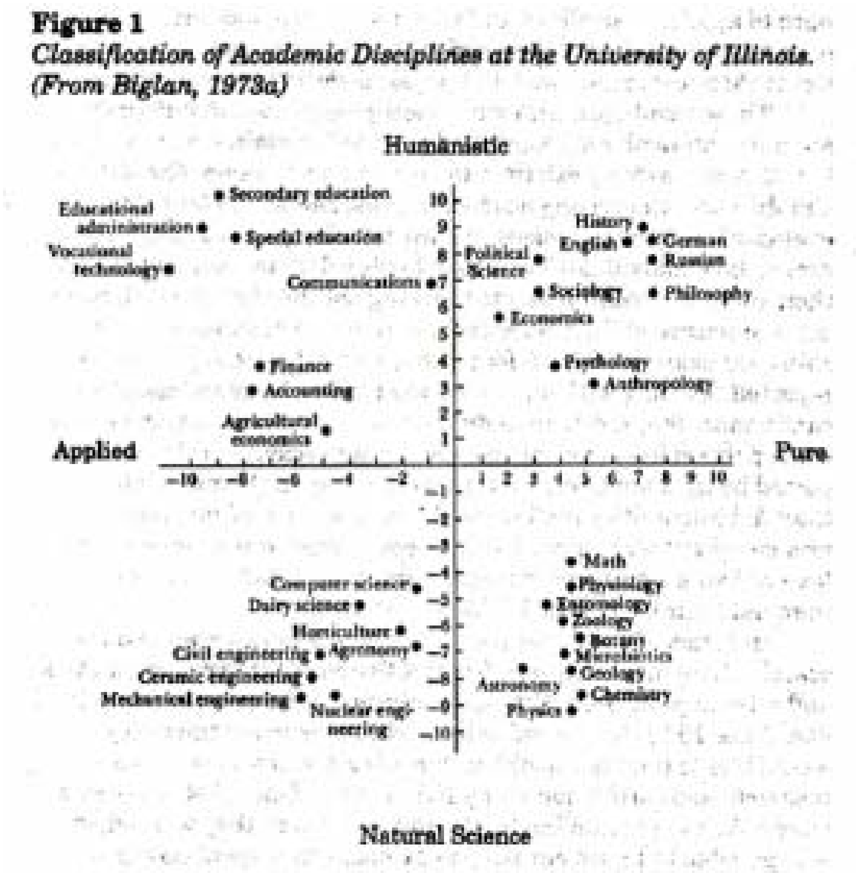

Figure 1 – Classification of academic disciplines from the University of Illinois, 1973

As can be seen, the upper right quadrant deals with disciplines that characteristically have been termed the humanities, together with a smattering of social sciences. The lower right quadrant contains the sciences and mathematics, with specific disciplines ranging from physiology to physics. The lower left quadrant contains applied disciplines that deal largely with the physical world whereas the upper left quadrant contains applied disciplines that deal with the social world, primarily education and business.

It could be argued that since 1990, Systems Engineering has matured from a set of practices informally documented to a discipline with a body of knowledge that recognizes the contributions of non-engineering disciplines. Banathy (1999) believed that "A disciplined approach to engaging our creative energy calls for a level of understanding that crosses the boundaries between the humanities, the arts, the sciences, and technologies." An open question for future investigation is where should systems engineering appear in this matrix?

Comparison of the Systems Engineering Frameworks

This section returns attention to the systems engineering frameworks presented above. A number of observations can be drawn from Table 1. First, consider the number of activities checked for each framework, as provided in the final line of the table. If one considers 38 to be a ‘perfect score’, then one observes that only frameworks AT&T, GERDC, Planguage and INCOSE2 score 30 or more. Checking the dates of the sources, the first two predate 1970, and the fourth is an extrapolation from the ISO standard for systems engineering issued in 2002. This could suggest that as a profession, as we began to ‘solidify’ our practices, we also simplified them, at the risk of leaving out certain activities. However, it should be noted, that no two of these frameworks has an identical pattern of checked activities, and some of the frameworks are intended to focus on the development phase, versus the entire life cycle, viz., INCOSE1, SELC1 and Spiral. This substantiates critical advice given in all versions of the INCOSE Systems Engineering Handbook about the importance of tailoring any adopted practices before using them.

Next, consider the set of activities presented. The reader already familiar with some or all of these frameworks recognizes immediately that certain liberty has been taken by the author in categorizing the activities that appear in Table 1. For example, activity 5, Define Performance, appears in every framework, but is expressed in many different ways. Table 3 provides a sampling of the ways in which this activity is described in some of the frameworks, where the term ‘define performance’ is not explicitly used. However, the phase is found in the Vee, Planguage, NTNU, and INCOSE2 sources.

Table 3 – Expressions categorized as ‘define performance’

Framework	Expression
Reference	In the problem solving process, the hypothesis ("If *[I do X]*, then *[Y]* will happen.") must be constructed in such a way that it can be measured to support a subsequent test and conclusion.
SIMILAR	The ‘A’ in the acronym SIMILAR stands for Assess Performance. It is only logical that if performance will be measured, then the criteria have been defined.
Plowman	While never explicitly stated at the model level, the activities include conducting trade studies as a basis for informed decision making, which in turn suggests that performance criteria have been defined.
Tufts	Another framework that only hints at the definition activity by indicating an activity called ‘Manage Performance.’
INCOSE1	The list of essential steps includes ‘Establish Performance Requirements.’
AT&T	Hall states, “*Selecting objectives is the logical end of problem definition*.” (p. 9) The word ‘performance’ does not even appear in the index.
GERDC	Desired performance is initially referred to as “*… criteria on which the remaining work may be based*.” (p. 27)
SELC1	Under the heading ‘Definition of Operational Requirements’ is the category ‘performance and related parameters.’

Finally, Table 1 notes that the broad range of activities associated with managing a project have not been itemized as the author has categorized them outside of the scope of systems engineering activities, notwithstanding the plethora of literature on systems engineering management.

Systems Engineering Meta-model

This careful collection of frameworks and their comparison has been conducted with the intention of teasing out common attributes that might provide some insight into the real work of systems engineering. The author has distilled this into a meta-framework she calls the 6C's of systems engineering, so named for the following characteristics: Comprehension, Communication, Coordination, Collaboration, Cooperation, and Continuity.

Comprehension. This word was originally 'understanding,' which really ruined a fine pattern of words beginning with the letter 'c.' Many of the activities listed in Table 1 require the systems engineer to be knowledgeable in a domain, and otherwise able to understand, in a complete way, the information shared by the stakeholders. Jack Ring has stated, "As systems engineers our value is manifested in our ability to comprehend 'the problem' …" (Ring, 2002; 19). Chestnut writes, "The approach one uses in solving a problem is greatly influenced by his understanding of it." (Chestnut, 1967; 104). Kossiakoff and Sweet (2003) talk of the power of multidisciplinary knowledge, and Banathy (1996) calls social systems design a multidimensional human activity of disciplined inquiry. All of which adds up to a person who listens well, can empathize with underlying value systems, and brings a broad personal knowledgebase to the work of systems engineering.

Communication. All of systems engineering activities require good communication skills. Chase describes this facilitation in this way, "In fact, it must be stressed that a participant in an integrated system design effort… must, therefore, be able to use a commonly understood system-oriented language, and not just his specialist-oriented jargon, which when employed by any number of specialists in relation to a systems-oriented context, and result only in a babel of tongues." (Chase, 1974; 21) Kossiakoff and Sweet also use the 'Tower of Babel' analogy. This powerful influence on the outcome of an endeavour has also been recognized in other disciplines, for example, Conway's Law. Endres and Rombach emphasize this point by observing, "Conway's law is valid since system development is more a communication problem than a technical problem. It is more important to think about communication barriers and enablers than about tools that enhance the clerical or intellectual capabilities of the individual." (Endres and Rombach, 2003; 82) Try to find a job description today that does not include the catch phrase, 'good oral and written communication skills.'

The next three characteristic may seem very similar, but each deserves to be included on its own merits. Consider athletic endeavors, such as a soccer team. Each team member needs to maintain their own balance – or coordination of their body parts. As an entire group, the team cooperates toward the objective of scoring goals, and this is often achieved by executing well rehearsed sequences of plays in collaboration with team-mates.

Coordination. Coordination focuses on a harmonious functioning of parts for effective results.[15] This attribute was recognized by Sheard (1996) as the Coordinator Role of systems engineers. Hall begins his book by stating that "… effective systems engineering calls for careful coordination of process, people and tools. Such coordination cannot be learned from a book or set of books." (Hall, 1962; v) Chestnut goes further; "The interplay between the system engineer and engineering design specialist requires the closest coordination …" (Chestnut, 1967; 36) The Systems Engineering Handbook (INCOSE, 2006) agrees that coordination and communication create the biggest challenges for large projects, especially when the teams are distributed and can not meet face-to-face.

Cooperation. By cooperation is meant a group of persons working together toward a single defined objective, such as a soccer team, or a project organization. Kossiakoff and Sweet are very clear, "It is the systems engineers who provide the linkages that enable these disparate groups *[engineering specialists]* to function as a team. The systems engineers accomplish this feat through the power of multidisciplinary knowledge. … Through the ability to understand different languages comes the capability to obtain cooperative effort from people who otherwise would never be able to achieve a common goal." (Kossiakoff and Sweet, 2003; 25)

Collaboration. Collaboration is cooperation on a smaller scale. The term means working together with others, very often people or agencies with which one is not directly connected. This may be especially important when involving the stakeholders in a process. They may have a vested interest, but they exist, most often, outside the boundaries of the defined project team. Likewise, systems interfaces may require two or more separate firms to work together, facilitated by systems engineering oversight.

Continuity. System life cycles can be very long. One contribution that systems engineering can provide to a system is that of continuity. As an example, the Systems Engineering Handbook (INCOSE, 2006) lists continuity in configuration and traceability. In products, such as automobiles, systems engineers are called upon to continuously upgrade the capabilities of a product to take advantage of technological advances, or to modify components in response to changing legislation regarding safety or pollution control, to name two examples. Sage (2000) refers to this as 'knowledge brokering.'

This characteristic is also tightly connected to the need for good decision-making throughout the life cycle. Kossiakoff and Sweet express it this way, "The systems engineer is always the advocate of the total system in any contest with a subordinate objective." (Kossiakoff and Sweet, 2003; 14)

Code of Ethics. It should be stated explicitly that the 6C's sit in a context of a code of ethics. Systems engineering practitioners have a moral obligation to serve the higher needs of society. The INCOSE Code of Ethics for systems engineers states, "The practice of Systems Engineering can result in significant social and environmental benefits, but only if unintended and undesired effects are considered and mitigated. … [Systems engineers] guard the public interest and protect the environment, safety and welfare of those affected by engineering activities and technological artifacts." [16]

Framework mapping. Table 4 maps the activities of Table 1 onto the attributes of this meta-framework of systems engineering. Some of the activities map to more than one attribute. While the attributes appear in no predetermined sequence, the order may reflect the author's bias for which attributes are most needed or exercised by an activity. Table 4 represents a first attempt to consider the activities of systems engineering in terms of abstract human activity rather than concrete artifacts of the process or methodology employed (Friedman and Sage, 2004).

Table 4 – Mapping of activities onto meta-framework attributes

Activity	**Attributes of Systems Engineering ***
Identify stakeholders	Collaboration, Comprehension
Formulate the problem	Collaboration, Comprehension, Continuity
Define requirements	All
Investigate alternatives	Collaboration, Comprehension, Continuity
Define performance	Collaboration, Comprehension, Continuity
Requirements Analysis	Collaboration, Comprehension, Continuity
Model the system	Comprehension, Coordination, Cooperation
Define functions	Comprehension, Coordination
Engineering design	Coordination, Continuity
Design Architecture	Coordination, Continuity
Assess and manage risk	Collaboration, Comprehension, Cooperation, Continuity
Implementation	Collaboration, Cooperation

Activity	Attributes of Systems Engineering *
Manage interfaces	Coordination, Collaboration, Cooperation
Integration	Coordination, Collaboration, Cooperation
Define tests	Coordination, Collaboration, Cooperation
Verification	Coordination, Collaboration, Cooperation
User Training	Collaboration, Cooperation
Production support	Coordination, Collaboration, Cooperation, Continuity
Transition	Collaboration, Cooperation
Validation	Coordination, Collaboration, Cooperation, Collaboration
Operational support	Coordination, Continuity
Maintenance	Coordination, Collaboration, Cooperation, Continuity
Replacement, upgrade	All
Retirement, disposal	Coordination, Collaboration, Cooperation, Continuity
Manage baselines	Coordination, Collaboration, Cooperation, Continuity
Manage project	All
Conduct reviews	All
Maintain documentation	Continuity
Manage information	All
Address legacy systems	Comprehension, Collaboration, Coordination
Manage complexity	All
Capture business plans	Comprehension, Collaboration, Continuity
Manage quality	Coordination, Collaboration, Cooperation, Continuity
Integrate disciplines	All
Acquisition	All
Supply	All
Continuously re-evaluate	All
Environmental impact	Comprehension, Continuity

* Note: Communication maps onto all activities

Figure 2 illustrates a relative weighting of the 6C's based on their frequency of appearance in Table 4. The radar diagram indicates that Communication is the most frequently exercised attribute, followed closely by Collaboration.

Coordination, Cooperation and Continuity are very similarly weighted. Comprehension is listed least often – but this does not mean the brain is not engaged for every activity, just that certain activities require more concentration to achieve understanding.

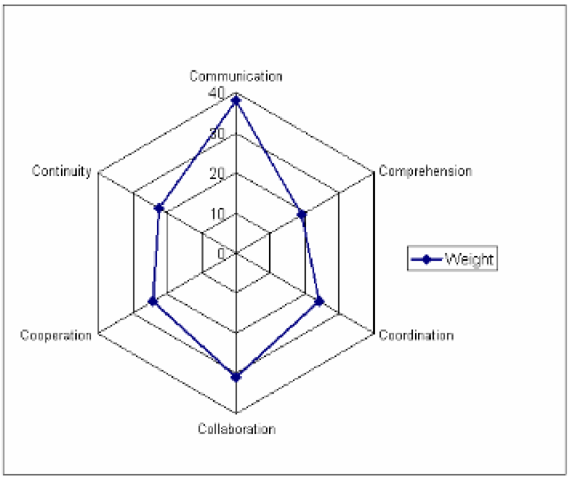

Figure 2 – Radar Diagram of the 6C's Framework of Systems Engineering

The intention of creating a meta-framework of systems engineering activities is to address the contention that there are classes of problems to which systems engineering does not apply, and that this includes systems with exclusively social objectives (Checkland, 1999).

Systems Engineering Practices

At issue is the question, is there a class of problems to which systems engineering does not apply? The quick answer is, probably. The aforementioned principle of scalability suggests that projects of a certain size, specification and complexity do not require full-scale systems engineering. This is not the same as saying that such projects do not benefit from a systematic approach to design or construction, but only that many of the 38 activities listed in Table 1 would not be necessary, and tailoring a systems engineering process could result in using only a handful of activities. But to-date there is no formal definition that indicates the tipping point at which systems engineering should be applied to solving a problem.

This question is further complicated by the existence of numerous brands of systems engineering in the literature. Hard, soft, cognitive, industrial, information, and software are adjectives often appended to the front of systems engineering. And it does not stop there, it is possible to find literature on applied, aero, control and ocean systems engineering, just to name a few that will not be discussed here. The adjective 'hard' generally applies to using systems engineering as a systematic approach to solving problems using model building and simulations and many of the activities listed in Table 1. Soft systems methodology is the term adopted by Checkland to differentiate his approach from the former to address perceived deficiencies in problem formulation. This method exercises soft skills, such as the ability to engage in negotiation or dialogue, to establish an environment of trust, to network, and to facilitate process or change management. Cognitive systems engineering focuses on how man interacts with the environment and draws from experience and research in both cognitive psychology and hard systems engineering. Industrial engineering is often found in academic settings in departments of systems and industrial engineering. This may be explained by the fact that both disciplines are concerned with the development, improvement, implementation and evaluation of integrated systems of people, money, knowledge, information, equipment, energy, material and process.[17] Information systems engineering applies computer science and human cognition theories to the management and design of computer-based information systems. Software systems engineering has close parallels to hard systems engineering with a focus on software systems – which also suggests some overlap with information systems engineering.

DeRosa (2005) introduces Enterprise Systems Engineering to focus on some the difficulties of "beginning with a specification" by presenting approaches for creating initial specifications and thereby addressing one of Checkland's primary objections to hard systems engineering. These early efforts to produce a specification also have been described by some as the 'dark side of systems engineering' because, until recently, it was rarely discussed (Fossnes, 2007).

Contributions from socio-technical systems theory[18] advise that humans in organizations should have roles that are complementary to machines as opposed to humans being extensions to machines – such as a clerk who inputs data all day long but has no connection to how the data is used. Likewise, the design of such systems should reflect an optimization of both the social and the technical elements of the system – for example, the same or different people should not be feeding the same information into different computer-based systems.

Kossiakoff and Sweet (2003) describe two different sources for engineering activities in the automotive industry. One is described as socio-driven need or new constraints on the product that are placed on the manufacturer by the environment. An example of this is new rules from regulatory or legislative bodies that determine the demand for fuel economy, safety, pollution control, and after-life reclamation of parts. On the other hand are the techno-driven needs, which are usually self-imposed changes to integrate technological advancements that make the product more interesting, safer or less expensive to produce. An example of this type of change is the recent explosion of computer technology found in modern automobiles.

Most systems will benefit from a combination of hard systems engineering with extensions that incorporate the intentions of soft systems methods as illustrated in Rees (2000). The reason for this is that the problems to which systems engineering is applied can be classified as ‘wicked’ problems. Kasser (2007) provides a summary of what is meant by wicked problems. He reports on an informal survey against the themes of the published papers of the INCOSE annual symposium and finds also that despite increasing attention, socio-economic systems was the least addressed theme. This result is consistent with Haskins (2008) and can easily be explained by the demographics of the INCOSE membership, which is primarily employed in the making of ‘well-defined’ systems. However, this indicates a potential to improve our membership profile by attracting more systems engineers with an interest and concern in social challenges.

Empirical applications of systems approaches to social challenges

Checkland (1999) maintained the distinction between ‘hard’ and ‘soft’ systems thinking with the former being more appropriate for technical well-defined problems. This view is not well aligned with the bulk of systems engineering literature, whose authors would love to return to the days of non-trivial technical systems that could be defined well, if those days ever existed.

While he was president of the International Society for the Systems Sciences, Banathy (1999) observed, “Unique to our age is the massive scale at which we are applying science and technology to the construction of our physical, social, and cultural reality.”

In his newly released book, ‘An introduction to systems science,’ Warfield opens with a list of bad practices that his book intends to remedy, including a criticism of much of systems literature, “It offers either theory with no empirical evidence, or (less commonly) empirical evidence with no supporting theory, or now and then, sheer fantasy with neither theory nor evidence; thereby at least giving some relief from monotonous bifurcation.” (Warfield, 2006; vii) He attempts to compensate for the dearth of empirical evidence with contributions from other authors about their experiences applying systems science. “It was my intention in inviting these authors to try to obtain a sufficient variety in both locale and subject matter to help show that the idea of systems science as a neutral science was a valid concept…” (Ibid; xi) He dedicates a chapter each to contributions from four sectors, which he labels private, government, social, and education. Each of the three stories that appear under the chapter for the social sector relate a history of the use of the Interactive Management method in a social setting, from peace-building efforts in Cyprus to citizen involvement in local planning in Mexico and Latin America. From the latter account, Professor Moreno asserts that the structured participation of individual citizens is one of the most relevant challenges for development today.

Haskins (2007) has reported on case work conducted in Verdal, Norway in which she applied a systems engineering framework called iFACE to help residents of an industrial park establish a vision for their further development.

Fet (2004) conducted a project in Klaipeda, Lithuania, to map and evaluate the environmental performances of 10 industrial companies and the local community by using systems engineering methodology.

Karl-Henrik Robèrt founded the Natural Step to help others achieve their sustainability goals. His implementation methodology is called Strategic Sustainable Development and contains many activities found in Table 1 (Robèrt, et. al, 2002). Thesis projects demonstrating this approach are available online.[19]

Pat Hale, in describing the INCOSE participation in the GEOSS consortium, reported that GEOSS is typical of problems that systems engineers will face in the future, "in addition to technical complexity, GEOSS has disciplinary and domain complexity. GEOSS is an 'engineered system,' but no solutions exist without politics, economics and sociology, etc."[20]

Implications for educating systems engineers

Dörner provides a comprehensive exposition of the "inadequacies of human thought in dealing with complex systems." (Dörner, 1996; 185) He recounts many examples of exercises in which traditional problem solving approaches do not yield the desired results. He proposes that faced with complexity, humans simplify, focus on what we think we understand, and proceed with full speed to a conclusion, all in an effort to use our scarce 'thinking' capabilities as efficiently as possible. Another reason he offers is the amount of time it takes to assimilate new material. This has also been expressed as the Librarians Law: "The more knowledge that is available, the more effort has to be spent on the processes to use it." (Endres and Rombach, 2003; 228) It should come as no surprise that we are trounced by the Law of Unintended Consequences when we know so little at the time of decision-making.

This suggests that it is time to look more closely at the teachings of the thought leaders who have for decades straddled both the systems and software engineering divide. Both Tom Gilb, the inventor of Planguage, and Barry Boehm, the author of the spiral model, have long understood the value of combined iterative and incremental processes as a way to reduce risk in the face of uncertainty, and to learn by doing in the face of unclear objectives. Asbjørnsen (1992) describes the iterative nature of the problem solving process. When faced with an 'unsolvable problem' the next step in the process is to redefine the problem, presumably with the blessing and participation of our stakeholders.

Sage (2000) itemizes 12 deadly systems engineering transgressions. Two of them are particularly relevant to this discussion.

> *#3 There is a failure to develop and apply appropriate methodologies for issue resolution that will allow identification of major pertinent issue formulation elements, a fully robust analysis of the variety of impacts on stakeholders and the associated interactions among steps of the problem solution procedure, and an interpretation of these impacts in terms of institutional and value considerations.*
>
> *#9 There is a failure to properly relate the system that is designed and implemented with the cognitive style and behavioral constraints that effect the user of the system, and an associated failure of not properly designing the system for effective user interaction. (Ibid; 168)*

Banathy (1999) believed that "A disciplined approach to engaging our creative energy calls for a level of understanding that crosses the boundaries between the humanities, the arts, the sciences, and technologies." Van Berkel (2000) makes a case for integrating environmental and sustainable development agendas into multidisciplinary education.

Reconsidering the librarian's law, this means that there is a lot to learn, and as multi-disciplinarians, systems engineers need more than ever to be generalists who understand underlying principles without being able to solve a given problem alone. This has serious implications for educational institutions. For example, NTNU is looking into the establishment of a 5 year Master's level degree program in 'systems engineering' to give the student a chance to assimilate a broad range of learning. This activity is still in the investigation stages, but hints at an approach that may alleviate the time constraints.

Another approach has been advocated by MIT where a new field of Engineering Systems has been defined as a superset of disciplines incorporating both engineering and management sciences and including Systems Engineering as an underlying discipline. The new field of Engineering Systems addresses some of the criticisms levied against systems engineering and expands the vision to encompass developing "sustainable engineering systems with optimised value to society as a whole." (Rhodes and Hastings, 2004: 4)

So where does this leave us? Empirical evidence does not give us any indication that systems engineering can not be applied to any class of complex problems. The evidence does suggest that our 'tool box' may need to expand to include tools not normally taught in engineering courses of study, such as in the disciplines of psychology and economics, to name two.

Conclusions

There has been a paradigm shift in modern science. Pulm (2005) summarizes it succinctly as follows, "… from Newton to Bergson, i.e., from mechanistic universe to intuition and creativity, from atomistic to holistic, from observation to participation, from one best solution to many good solutions, from prognoses to scenarios, from representations to constructivism, or from destructive to creative chaos."

When one considers how long systems thinking has been recognized – both Warfield (2006) and Checkland (1999) trace works back to the early Greeks for Western Civilization – the question emerges "Are we any nearer to using systems concepts to make the really important decisions?" such as those made by national and local governments. Notwithstanding periodic articles with optimistic titles like "Systems thinking is back on the agenda," (Hauck, 2005), this author agrees with Wolstenholme (2000) that there is still a long way to go.

The primary contribution of this paper is the summary and comparison of twelve modes of systems engineering as taken from the current literature, and the subsequent abstraction of a systems engineering metamodel. This paper also provided a critical assessment of the status of systems engineering as a discipline. Using examples from the literature, the author has demonstrated that there have been both successes and failures in the application of systems approaches to the solution of social and socio-technical problems. This suggests the need for extensions to the current curricula for engineers and systems engineers in particular. Future research should consider whether working with a definition of systems engineering from a more abstract set of perspective, such as the 6C's, will expand the flexibility of both the practitioners and the range of problems tackled, opening the way for the acceptance of systems engineering as a valid approach to addressing environmental issues and global challenges.

A propos, Dörner (1996) reported on a study of decision-making under crisis conditions. In this study, the participants acted under the principle of 'the ends justify the means' rather than their personal moral standards. Under such circumstances, redefining the problem will give less than just results. If the 'unsolvable problem' at hand concerns a product with a negative environmental effect and the only 'affordable' option is continuing without correcting the flaw in order not to loose the estimated product income then redefining the problem to eliminate concern for the environment should not be an option.

One could wonder whether new understanding about the impact of man-made systems on the planet combined with new technologies will be enough to halt the inevitable cataclysms currently forecast. As a body of educators, researchers, and professionals we need to step back and consider our potential contributions. The time has come to define *'principled' systems engineering* for the 21st Century.

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Paper E.

Using the concept of sustainable development to encourage corporate social responsibility in industrial park tenants

Paper in Progress

Using the concept of sustainable development to encourage corporate social responsibility in industrial park tenants

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Abstract

This paper reports on a project entitled Building for the Future conducted in an industrial region in Norway. The project examined the recent history of growth and sought to identify ways to continue the growth into the next decade while encouraging a stronger commitment to corporate social responsibility in all the tenants. This paper observes that the literature of corporate social responsibility is primarily addressed to the multinational or large corporate audience. Research shows that the small and medium enterprises are not engaged in the sustainability or corporate social responsibility dialogue. This paper explores the implications of this exclusion and alternative methods for involving smaller firms. Results from a case study are used to illustrate one way to encourage interest in corporate social responsibility by using sustainable development as a communication medium. The paper presents a matrix for describing the stages of progression toward sustainable development.

1 Introduction

The language of sustainable development and corporate social responsibility is becoming increasingly intertwined. The terms themselves are 'appraisive' in nature (Moon, 2007) – no one deliberately seeks to be assessed as unsustainable or irresponsible. On the other hand, most companies do not appreciate externally generated solutions that imply that they can not run their own business properly.

The background and histories of the concepts of sustainable development (Lamberton, 2005; Mebratu, 1998; Pezzoli, 1997; Robinson, 2004) and corporate (social) responsibility (CSR) (Carroll, 1999; Dahlsrud, 2008; Doane, 2005; Korhonen, (2003)) are well discussed (and debated) in the literature. The language used to discuss these concepts has fused into a profusion of terms sometimes used interchangeably, such as triple bottom line (TBL), sustainability, corporate citizenship, social responsibility, greening supply chains, and corporate accountability to name a few. But, to-date, the primary audience for the 'CSR business case' is multinational corporations (MNC) and large firms with concern for not only the economic benefits but also the reputation and image implications (Luetkenhorst, 2004). The majority of small to medium sized enterprises (SME) are generally not addressed in this dialogue. For example, a sampling of tenants in a rural Norwegian industrial park indicated that the majority had never heard the terms corporate social responsibility or sustainable development as recently as January 2007 (Haskins, 2007b).

This paper opens with an overview of the concepts of CSR and sustainable development, and their foundations in environmental performance reporting. Next, the paper reports on findings from a case study during which the principles of sustainable development were used to introduce corporate responsibility to the tenants of an industrial park. The paper offers a matrix for describing the stages of progression toward sustainable development as a mechanism of self-assessment for SMEs.

2 Background

2.1 Sustainable Development and Corporate Social Responsibility

In business literature, sustainable development is also referred to as the triple bottom line to reflect the simultaneous focus on social, economic and environmental concerns this challenge imposes on corporations. Abbreviated descriptions take the form of the 3E's – equity, environment and economy – or the 3P's – people, planet and prosperity (Zimmerman, 2005). Evidence of unsustainable development abounds. Every day the media reports on yet another lost species, depleted stocks of non-renewable resources, imbalances in global consumption patterns, or imbalances in access to food, water, and medical attention. To this end, sustainability is a balancing act and most indicators of sustainability are really measures of imbalance, intended to warn us when the delicate planetary equilibrium is upset (Dahl, 1996; Fricker, 1998).

SMEs are described as the lifeblood of most economies (Borga et. al. 2006; Castka et. al. 2004; Luetkenhorst, 2004). Fox (2006) discusses the variety of what constitutes a small, medium or large company, and the fact that there is no clear definition – not even within individual nations. The range encompasses established family concerns that might employ over a hundred people, to the informally self-employed. For the purposes of this paper, the term SME will refer only to firms legally registered with their respective nation.

CSR discourse rarely focuses on the SME; tools, frameworks and argumentation in favor of CSR focus on large enterprises, except indirectly when an SME is a supplier to or beneficiary of a larger company's initiatives (Kuhndt, 2002). In the case of a SME acting as a supplier, the ability to conform to CSR reporting requirements is often a condition of 'sale' and no longer a 'voluntary' activity.

The World Business Council for Sustainable Development (WBCSD, 1999) describes CSR as the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large. Corporations are often the agents by which development is enacted. "Responsible business is a necessary but not sufficient condition of sustainable development." (Moon, 2007; 305) Spangenberg (2007) refers to command-and-control management as first order governance, and the methods that combine more participative involvement from stakeholders and management as second order governance. This principle is illustrated by changes in the approach to sustainability over the past three decades as companies accept increasing responsibility for the impacts of their production and manufacturing operations. These changes are partly motivated by increased demands for transparency from shareholders and the public. Table 1 summarizes the shift in focus over time as companies evolve from what is legally required to what is financially justified and, most recently, toward "global norms of integrity, ethics and justice" (White, 2005: 6).

Table 1: Emergence of Corporate Social Responsibility

Event	Drivers	Responses
Stockholm 1972	Command and control	Compliance with legal regulations
Rio de Janeiro 1992	Co-regulation and cost/benefit analysis	Cleaner Production
Johannesburg 2002	Collaboration; norms of ethics and justice	Corporate Social Responsibility

During the 1972 Stockholm Conference - United Nations Conference on the Human Environment - the focus was on international cooperation on the environment. The initial reaction by governments was to use regulatory mechanisms to establish constraints on business toward meeting the environmental goals. The reaction from business was defensive, achieving compliance at best. Twenty years later at the 1992 Rio Conference - United Nations Conference on Environment and Development – the focus shifted to the broader issue of the relationship between environment and development at the national and international levels. At the same time technology offered new methods for achieving cleaner production, and business realized that they needed to take a proactive stance toward sustainability. The Johannesburg Summit - World Summit on Sustainable Development – took place in August/September 2002. Today there is consensus around the general concept of sustainable development and that its three pillars - economic, social and environmental - must be integrated in a balanced way. With this comes the realization that in the era of globalization sustainable development can only be achieved through close partnership between Governments, the private business sector and civil society. Currently the banner of CSR is leading the crusade for more equitable and sustainable development. But CSR, as it is discussed today, is firmly routed in the foundations of environmental management and reporting.

2.2 *Environmental performance levels and management tools*

A model of the levels of environmental performance is shown in Figure 1. The horizontal axis is the time span of a product's lifetime with its phases planning, manufacturing, use and disposal, and then the human lifetime extending to the intergenerational span of civilization. The vertical axis indicates the scope of the environmental concern, ranging from a single product life cycle, to all the products made by one manufacturer, gradually encompassing all manufacturers and the whole of society. The shaded and numbered areas represent the scope of environmental performance at different levels:

1. Environmental Engineering (includes various types of engineering and production)
2. Pollution Prevention (limited to product production and planning)
3. Environmental Conscious Design and Manufacturing (concerns the entire life cycle of a product including the distribution, the use and end of life treatment of the product)
4. Industrial Ecology (concerning several producers in a long term perspective, e.g. an industrial park located in a region)
5. Sustainable Development.

As shown, sustainable development (SD) is concerned with the environmental impact of any activity on society as measured in the span of human history. A sustainable industrial park, for example, would be expected to survive many generations, with a cumulative positive impact on society.

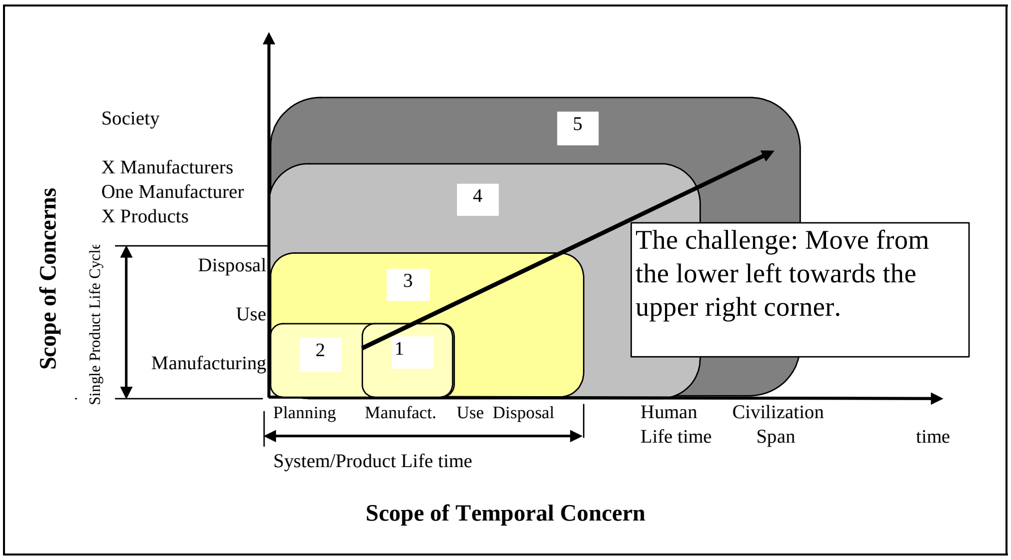


Figure 1: Classification of environmental performance levels (Fet 1997, modified after Bras, 1996)

Different environmental management tools have traditionally been used to help companies to move toward sustainable development. The best-known are Cleaner Production (CP), Environmental Accounting (EAc), Material Flow Analysis (MFA), Life Cycle Assessment (LCA), Design for the Environment (DfE), Environmental Auditing (EA), Environmental Performance Evaluation (EPE), and Environmental Management Systems (EMS).

Figure 2 shows one way of applying the tools on the different performance levels shown in Figure 1. Each of the companies co-located in an industrial park will most probably be operating at a different performance level. A movement towards SD will therefore require the use of different methodologies. However, instead of working with different methodologies for each tenant in the park, Systems Engineering is shown to be an overall methodology (Fet, 1997). Systems engineering is the foundation for SPADE (Haskins, 2007a), see Figure 3.

SPADE is a conceptually simplified methodology that makes the advantages of systems engineering accessible to a wider audience of users. The methodology provides a systematic approach to problem solving that incorporates the tools and methods of environmental management, as listed above, systems engineering and participatory approaches to problem definition and decision-making.

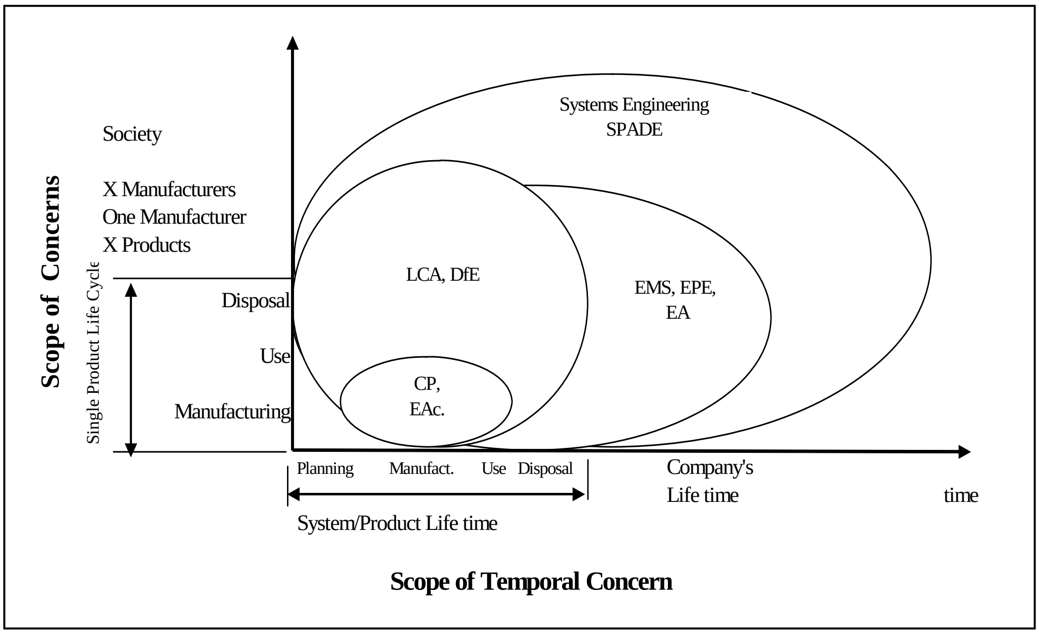
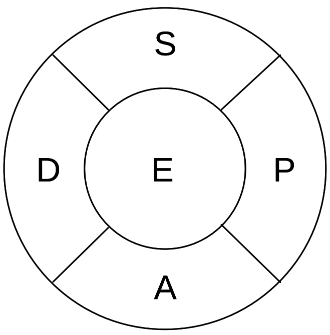


Figure 2: A classification of methods and tools for environmental performance improvement (modified after Fet, 1997)



S	Stakeholders – continuously search for those who influence or are influenced by the 'system'
P	Problem – continuously work to understand the needs of the stakeholders and address conflicting needs; analyze the current situation and hypothesize about alternative futures; establish measures of performance and success criteria for evaluation
A	Alternatives– continuously generate options that address the problem as currently understood; consider both high and low technology approaches
D	Decision-making – continuously integrate new solutions or activities that work toward resolving the problem and satisfying the stakeholders
E	Evaluation – continuously – this activity touches all other activities; use measures of performance and success criteria

Figure 3: SPADE graphical representation and definition (Haskins, 2007a)

3 Reporting mechanisms and performance indicators

The Global Reporting Initiative (GRI) is associated with public reporting mechanisms. Brown and Fraser (2006) identify two types of motivation for companies to report on their social and environmental performance*; the business case* and *the stakeholder-accountability* arguments. Porter and Kramer (2006) divide the business case for corporate responsibility into four categories; *moral obligation* (to 'do the right thing'), *sustainability*, *license to operate*, and *reputation*. Advocates of accountability insist that transparency is essential in democratic societies. Critics of both approaches point out that as long as reporting is based on neo-classical economics voluntary reporting will not bring about the desired change and citizens are better off relying on whistle-blowers and watchdog agencies. Many believe that industry will play an important role in the sustainability transition (Angel and Huber, 1996; Doane, 2005; Lamberton, 2005).

Korhonen (2003) criticizes the single-firm orientation of most business reporting mechanisms and proposes that to avoid the risk of problem displacement a network approach should complement individual firm management and reporting. Without the larger systemic perspective, such as provided by Systems Engineering and Industrial Ecology, company level reporting fails to account for unintended consequences such as the rebound effect and Jevons paradox, whereby increasing efficiency results in an increased use of non-renewable natural resources (Brattebø, 1996; Lowe et.al. 1997; Fiksel, 2006).

Performance indicators are a part of the GRI reporting guidelines. With the issuance of the G3, or third generation of guidelines issued in 2006, the GRI is beginning to address the reporting needs of SMEs.

The G3 performance indicators are grouped in three categories, economic, environmental and social. The last category is further divided into four sub-categories; Labor Practices & Decent Work, Human Rights, Society, and Product Responsibility. However, some reporting organizations are also developing their own indicators. It is challenging to create indicators that are both generic and locally meaningful and acceptable to company leaders and their stakeholders (Kuhlman, 2007; Spangenberg, 2007). There are formal requirements that apply to the development of indicators. They should be observable and quantifiable; sensitive to change; transparent and easily understood; and robust against manipulation (Øien and Sklet, 2001; Mog, 2004).

4 Progression toward sustainable development

The challenge facing any company, but especially SMEs that have smaller budgets for investment, is where to start on the progression toward sustainable development. What is needed is a simple explanation of the steps a company needs to takes to meet sustainable development goals, without being overloaded with the wealth of theory and principles from the academic literature. First, sustainable development is placed in a larger context that includes non-sustainable development as illustrated in Figure 4.

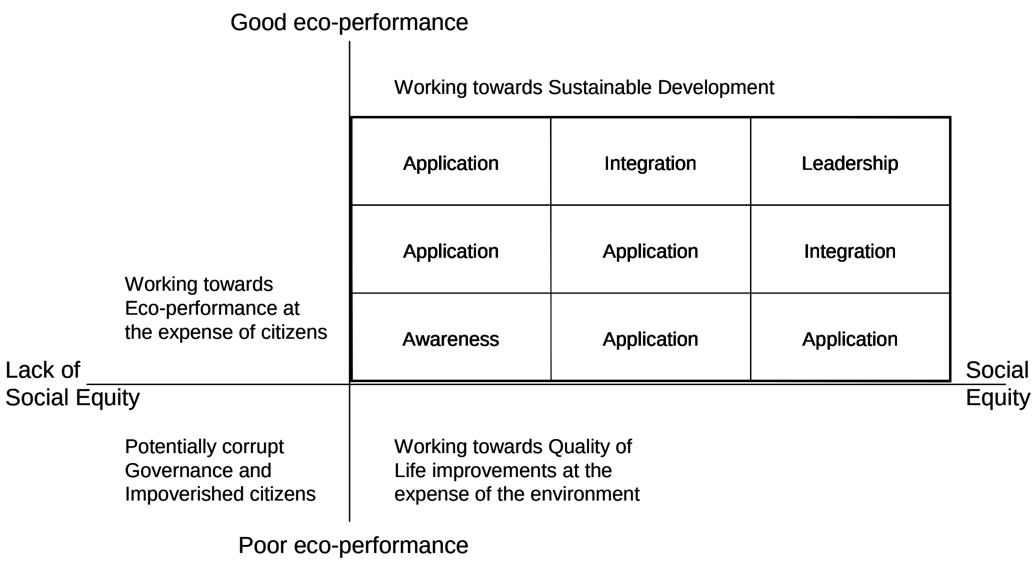


Figure 4: Context matrix of sustainable development

The context matrix is constructed using the three pillars of sustainable development. The social element is indicated along the x-axis of the frame; a combined performance in economic and ecological issues, along the y-axis. Placement along the y-axis is determined by the degree that a firm acts deliberately, according to a plan or strategy, versus 'accidentally' or tactically, to protect natural environments while remaining profitable. Each quadrant defines an attitude about sustainability, with the upper right hand quadrant reserved for companies (or governments) that are working toward sustainability. Second, an additional matrix is positioned in this quadrant to further define the stages of progression toward sustainable development.

As shown, the four stages of progression are Awareness, Application, Integration, and Leadership. A company can be seen to pass through these four stages as they work to achieve sustainable development goals while simultaneously maintaining a healthy firm. The managers of a firm pass through each of these stages in their commitment to sustainable development. Table 2 defines each stage and a set of actions.

Table 2: Definition and actions for the four stages of progression toward sustainable development (SD)

Stages	Managers achievement	Action
Awareness	Knowing how the firm is performing today and recognizing that there are areas where improvements can be made.	Open dialogue with employees on hiring, salary and safety conditions; install energy saving devices; establish and follow-through on recycling initiatives
Application	When the managers begin to take decisions that improve the performance of the firm toward the environment, and regarding the welfare of its employees,	Align hiring and salary policies; improve the safety of work conditions; monitor employee satisfaction; minimize use of virgin, non-renewable raw materials; introduce reuse practices; move toward cleaner production; measure and track emissions; conduct life-cycle analysis assessments of environmental impact of products and processes
Integration	In this stage, the managers integrate concern for the environment and society with their responsibility to create profit. They create strategy and company-wide programs that achieve objectives in all areas.	Strategic planning; firm adopts and practices EMS and SD reporting practices; transparent stakeholder relationships; equitable hiring and salary practices; excellent working conditions; continuous education to maintain and enhance workforce capability; attention to environmental impacts extends to the supply chain; invest to redesign product and production methods to achieve best eco-performance
Leadership	A company that has consistently performed well and acts as a champion for economic-environmental-social accountability can be seen as a leader and role model for others who would achieve the same goals.	Encourage by example; active role in local community; continuous practice improvement; production approaching zero emissions; proactive raw material replenishment program; tight relationships with local communities; financial and CSR reports are combined

5 Case study

The matrix of progress toward sustainable development evolved from a case study of a rural Norwegian community (Haskins, 2007b). The study was conducted in four phases. Each phase is presented with its objectives and results.

5.1 Phase 1: Design the survey

During phase 1, the managers of the VIP identified a desire to begin 'greening' the VIP. They were uncertain how such a proposal should be communicated or how the tenants of the VIP would react to this idea. Extra questions were inserted into an annually administered survey to test the attitudes of the CEOs toward sustainable development concepts.

When completed the survey contained twenty-six questions and required approximately thirty minutes to complete. The questions on sustainable development were supported by the availability of a Norwegian translation of a book about CSR and sustainable development (Sjöberg et. al. 2003), which provided an official vehicle for communication and a motivation for the firms of the VIP to take these themes seriously. This meant that the survey served both as an instrument for gathering information from and about the local firms, and as an instrument for educating these leaders about the underlying principles of CSR and sustainable development.

5.2 Phase 2: Conduct the survey and interviews

During phase 2, the survey was distributed and the results were analyzed and validated by structured interviews. The primary purpose of the structured interviews was to confirm that the survey had been properly understood and answered. Candidates were selected based on diversity in the sectors and firm size as well as the age of the interviewees. The interviews were conducted with the interviewer speaking English. However, a Norwegian translation of each question was available to minimize misunderstanding of the meaning. Although formal questions were prepared, most interviews took the form of a conversation about the past, present and future of Verdal – and especially the industrial park.

5.2.1 Phase 2: Survey results

One hundred and twenty (120) leaders from VIP firms were invited to complete the survey. Of these, all except three would be categorized as SMEs, i.e., having fewer than 250 employees. VIP contains firms from a broad range of industries; however, nearly every industry sector was represented in the response population; 32% provide consulting and other services; 21% are from the construction industry; 21% represent light and heavy production combined; and 11% provide industrial sales. Over 70% of the firms that responded have always been located in VIP, and only 20% are part of larger concerns of which the VIP location is only one of many.

Analysis of the financial data records indicated that turnover and man-years of effort are closely coupled, although a slight economic down trend was observable in 2002-2003, which corresponds to the initial years of state financial support, meaning some early start-ups were able to operate at a loss. However, these figures also attest to the high productivity of these companies where each employee accounted for a minimum of 1 million NOK of turnover on average.

Two questions in the survey were designed to gauge if VIP firms are a good place to be employed; whether they recognize their social responsibility, and if they prioritize their stewardship of the natural environment. The validation interviews identified a bias in the questions towards firms engaged in heavy industry; e.g. questions about measuring and monitoring emissions, and this was taken into consideration in the evaluation of the results. Respondents were asked to rank the importance of a series of statements about the relevance of specified activities for their firm. Of the eighteen statements, eight were related to social actions toward their employees and the local community, nine toward environmental measures taken by the firm, and one general question about public reporting.

Table 3 ranks the importance of the social behaviors as evaluated by the responding firms.

In general, the social concern for employees within the respondent firms was excellent. Each of items #3-6 contained at least one response indicating they were unsure or had not thought about this topic before the survey. The questions about the local community, along with the concept of stakeholder, which was new for many of the SME respondents, were less well understood. Five respondents indicated that they had not thought about item #8 before the survey, and five were unsure how to classify the nature of their relationship to the local community (#7).

Table 3: Ranking of socially-relevant firm activities

Rank	Activity
#1	Provide good working conditions
#2	Open dialogue with employees concerning hiring, salary and safety
#3	Implement measures for monitoring/control and improvements in health, safety, and environment (HMS)
#4	Measure and follow-up employee job satisfaction in the workplace
#5	Offer continuous education opportunities to maintain and increase the competence level of employees
#6	Follow equal opportunity guidelines (equity in the workplace) regarding salary and hiring practices
#7	Maintain a close relationship with the local community
#8	Consider the local community to be one of the stakeholders of the firm

Table 4 provides a similar ranking for the environmental activities, and the public reporting.

Table 4: Ranking of environmentally-relevant firm activities

Rank	Activity
#1	Recycling initiatives are in place and used Products are made for reuse or recycling
#3	Active program to achieve cleaner production
#4	Green acquisition and attention to the environmental profile of our supply chain
#5	Measure emissions and maintain statistics
#6	Production operations use the minimum of non-renewable raw materials
#7	Energy-saving measures are installed throughout the locale
#8	Life cycle analysis is done to ascertain how our products impact the natural environment
#9	Investments are made to improve the eco-performance of our operations and our products

Many of the responses in this category indicated ‘unsure’, or ‘never thought of this before the survey’. In this category, only 20% of the respondents found the production-specific questions relevant; of these, 80% observed most of the eco-practices mentioned in the survey. However, the rankings are based on very low percentages, for example, only 38% practice “green” acquisition, which is ranked number four in Table 4.

The final sustainability question was related to the standards and certifications that respondent firms used. Only six respondent firms were ISO 14001 certified, which means they maintain an environmental management system, but six additional firms were considering moving in this direction.

5.2.2 Phase 2: Interview results

Recurring themes appeared in nearly every interview. The obstacles the CEOs perceived that prevented them from integrating sustainable development are summarized here.

- The SME firms felt that implementing an EMS would increase their overhead and they were reluctant to engage in non-essential activities without a good reason.
- In niche industries every one knows each other; reducing the pressure to formalize the engagements. In a small community, the citizens depend on watchdogs to blow the whistle if firms step out of line – or appear to present a hazard to the general welfare (Okkenhaug and Nesgård, 2007).
- In Norway, firms take HMS (Health, Environment, and Safety measures) for granted as a necessary part of doing business. Based on this, the VIP firms in full compliance with Norwegian law are already situated in the application stage along the ‘x’ axis of the matrix, see Figure 4. Movement further to the right is justified on the basis of extra efforts – such as promoting equity in overseas locations, or sponsoring initiatives in the local community.
- It can be hard to receive product declarations from others within the supply chain. When members of the supply chain are also part of the VIP community, the peer pressure provides enough motivation for all actors to behave in a correct way – be seen as a good corporate citizens – this creates the perception that reporting is redundant.
- The interviewees felt that Norway is behind the other Scandinavian countries with regards to environmental initiatives. Verdal follows the trends of Norway, but perhaps Norway could be doing much more.

5.3 Phase 3: Historical timeline

The search through the archival records was conducted while the surveys were being answered in order to construct a chronology of events for the period 1999-2006. This phase consisted of reading through a wealth of media sources and websites, as well as NTNU project reports (Irgens, 2002; Kvande, 2002; Kvarsvik, 2002; Opheim, 2002) to derive the timeline of activities taken between the lay-offs and the start of the research project. The data was augmented by historical records maintained by the Norwegian Statistics Bureau.

The historical timeline of activities between 1999 and 2006 included a range of activities, such as re-education and training for employees, creation of an incubator in buildings donated by Aker Verdal, and state financial support to assist in the creation of new jobs.

IndPro was formed initially in 1999 to promote new growth in the area through the acquisition of new tenants for the buildings deserted by Aker Verdal and finding businesses willing to build on open land. They formed the first industrial incubator opened in Norway to mentor the entrepreneurs who emerged when Aker Verdal began spinning off daughter companies as an alternative to providing all services through internal departments. These satellite constellations settled nearby, and this was the initiation of what is today know as Verdal Industrial Park (VIP).

Beginning in May 2002, Verdal received additional financial support from the state. This funding was allocated for a five-year period, during which the progress of growth in Verdal in the form of new start-up firms, and increased prosperity of existing companies has been tracked (Kvande, 2002). Recent research reports that this area has realized the highest rate of new firm start-ups in the entire country between 2000-2004 (Falstad and Nesgård, 2005).

Table 5 uses the SPADE framework to summarize the ways in which the activities of Aker Verdal and others led to the creation of the Verdal industrial park. This ‘after the facts’ mapping demonstrates the value of systems engineering as a unifying methodology to achieve the shared goals of the community.

Table 5: VIP creation mapped onto the SPADE framework

S	The stakeholders of the Aker Verdal crisis were initially identified to include the employees and any educational or governmental agencies that could contribute to retraining or otherwise supporting the employees as they learned new skills for new jobs.
P	In 1999, the problem was framed as a response to a crisis by creating an environment to stimulate economic growth and emerge stronger and less vulnerable to future change.
A	Employees and others were encouraged to bring their new ideas forward for consideration and nurturing in the incubator.
D	Many projects have been implemented – not all of them with equal success – but the attitude of IndPro, and the hopeful entrepreneurs, is to take risks and try new ideas out in the marketplace.
E	There are many records in the local media, in the academic literature, in the national statistics office, and in corporate reporting sources that evaluate the events of 2000-2006. These reports consider the social, economic and environmental changes that have taken place in the Verdal municipality.

5.4 Phase 4: Brainstorming a vision for the future

The objective of phase 4 was to solicit guidance from the VIP tenants about what steps should be taken next using participatory elicitation methods. Table 6 summarizes the vision of the CEOs who participated in the facilitated brainstorming sessions. The results have been structured to reflect the three pillars of sustainability; social, environmental and economic.

It is notable that during the initial meeting with the VIP tenants, only three of forty CEOs in attendance acknowledged having heard of CSR or sustainable development (in either English or Norwegian). When the study closed, six months later, sustainability had become a key element of the vision for the future of the VIP. For example, the CEOs who participated in the brainstorming session were willing to consider the possibility that environmental reporting and certifications had value as a condition for inclusion for future tenants of the VIP.

Table 6: Summary of brainstorming to define a vision for the future of the VIP

Social	Attractive workplaces – more aesthetic buildings More SMEs; no single firm with more than 500 employees Increased interactions and collaborations in the Innherred region
Environment	Better collective transportation offerings Must have permission to drive a car to VIP Focus on cleaner production Environmental certifications are a condition for being a tenant in VIP High-speed train connecting Steinkjer-Trondheim (1.5 hours) Cycle path connecting Tautra – Inderøy
Economic	Larger area zoned for VIP More single-family dwellings downtown Verdal Increased investment in cultural events Open a high mountain hotel in Vera Open a sea-side recreation area/bathing area in Ørin North Open a bird-watching center around RAMSAR area

The vision of the future that the VIP tenants see for themselves and the region will serve to guide future decisions and projects. In Table 7, the SPADE framework is used to summarize the current and future plans for the sustainment of the VIP.

Table 7: VIP sustainment mapped onto the SPADE framework

S	As the VIP continues to grow, the municipality, the citizens of the nearby town, visiting tourists, and nearby protected wetlands are incorporated into the context as stakeholders.
P	To understand their current situation and to envision a future state for the VIP, the leaders are engaging in a series of exercises, such as facilitated brainstorming. Every effort has been made to encourage the participation of as many stakeholders as possible.
A	The idealized vision of the future is being used with backcasting techniques to generate alternative courses of action, which in turn will define future projects.
D	Efficient techniques for evaluating projects and their potential for success have evolved over the past five years and will be applied to select future projects.
E	The intention has been expressed to retain contact with independent evaluators.

6 Discussion of the case study

Fet (1997) demonstrated the value of systems engineering as a unifying methodology to analyze environmental performance in the ship industry. The case study reported in this article (Haskins, 2007b) illustrates that the SPADE framework, derived from systems engineering principles, can provide a similar support to the tenants of an industrial park as they work together to progress toward sustainable development.

The survey revealed that 12% of the respondent have implemented EMS and are monitoring their environmental performance. Direct confirmation of the use of other methods and tools, as shown in Figure 2, was not obtained at this time. However, during the interviews there were references to supply chains and monitoring for dust and other undesirable by-products of production processes, which suggests that environmental performance is a concern of the CEOs for construction and heavy industry firms. More than 50% of the VIP tenants are in the services and consulting industries with products that are not generally associated with emissions or other environmental impacts. However, these CEOs could exercise more awareness about recycling, 'green' acquisition practices and closer attention to their office environments, as suggested by the survey results reported above.

During the interview, the CEOs were asked to assess the current stage of their company on the matrix of progression toward sustainable development. Twelve of the fifteen CEOs placed an 'x' on the matrix shown in Figure 4 and all ranked themselves in the integration or leadership stages. This is not unexpected since participation in the interviews was a voluntary activity, and undoubtedly those who self-selected may have been seeking validation that they were on the right path. However, most of the

CEOs needed to be encouraged to take credit for all of the positive actions that they were taking. Table 8 contains the self-assessment responses along-side relevant answers from the survey for each interviewed CEO.

Table 8: Stages of progression toward sustainable development in respondent VIP firms – interviewed, self-assessment (with researcher agreement)

N.	N. employees / industry sector	Locale in Verdal	Social / Eco-ranking (survey)	ISO 14001	Self-assessment
P2	40 / construction	Only site	High / High	NR	Integration
P3	4 / services	Only site	High / High	NR	Leadership
P8	4 / consultancy	Offshore mfg.	High / Medium	Evaluate	Integration
2	270 / construction	Use subcontractors	High / Medium	NR	Integration
3	40 /light industry	Only site	High / High	Evaluate	Integration
6	50 / consultancy	Only site	High / High	NR	Leadership
7	2 / services	Only site	High / Medium	NR	Integration
9	3 / services	Only site	High / High	Unknown	None
10	4 / other	Only site	High / Low	Unknown	Integration
11	65 / heavy mfg.	Part of larger firm	High / High	Certified	Leadership
13	5 / consultancy	Only site	High / Low	NR	None
16	6 / light industry	Only site	Medium/Medium	NR	Integration
17	1 / services	Only site	Unanswered	Unknown	None
18	8 / services	Part of larger firm	High / High	Unanswered	Integration
20	60 / construction	Only site	High / High	Evaluate	Integration

[mfg.-manufacturing] [NR-not relevant]

Use of the matrix as a self-assessment mechanism is not intended to replace use of the aforementioned environmental performance methods and tools. However, the matrix is easy to explain and understand, and gives a qualitative, if not quantitative benchmark for evaluating where a company is situated in their progress toward sustainable development.

When a case study demonstrates a good result, it can be difficult to remember the alternative scenarios that did not materialize. Research on the response of other rural communities to the closure or downsizing of a major employer has recorded a wide variety of consequences that range from few problems and only a mild negative downturn in economic prosperity to much more drastic effects (Leistritz and Root, 2002). Some communities have reported crippling downward spirals of lost employment coupled to reduced income and dwindling savings, loss of population in the affected region coupled to a reduction in the tax base, leading in turn to an inability of local government to maintain even basic services and infrastructure.

In short, the actions taken in Verdal created exactly the opportunities and environment for growth that mitigated the potential negative effects of the lost jobs. This has resulted in the creation of a VIP composed of a few large anchor companies and primarily SMEs. Luetkenhorst (2004) asserts that SMEs are critical to the well-being of society, especially outside large metropolitan population centers. The question is how to motivate SME owners to run their businesses in a responsible way and encourage them to report on their social, environmental, and economic performance.

7 Conclusion and directions for further work

Thought leaders in CSR question whether it is time to abandon the concept as having outlived its usefulness (Elkington, 2001; Luetkenhorst, 2004; Fox, 2005, White, 2005). One reason for this is the entrenched orientation of the CSR agenda towards larger and multi-national corporations. They argue that a different approach may be more effective in deriving contributions from SMEs toward sustainable development. Additional work is needed to define a reporting mechanism that will not overburden SMEs at the same time that it provides information suitable for comparison and analysis.

This paper has presented the results of a research project conducted in a rural Norwegian industrial park. The findings suggest that sustainable development can be explained clearly enough to motivate SME actors within the park to consider ways in which they can contribute to the overall sustainability of the industrial area and the local community. A reverse condition ensues in which the desire for sustainability suggests responsible corporate activities, both individual and in collaboration, that will enhance the future of the region. A contextual matrix is proposed as a way to visualize the stages a firm passes through as it increases its commitment to CSR activities on the pathway toward sustainable development.

The nature of the study does not support widespread generalization about how tenants of other industrial parks or members of other communities might react to the same message, but this suggests the subject for future research. Likewise, further work to generate a quantifiable scale for the matrix will result in a more robust mechanism for assessment and tracking of performance along the social and eco- performance axes.

Acknowledgements

The authors are grateful to the leaders of the VIP and all the tenants who participated in the survey and the follow-up interviews.

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