TOWARDS A LEARNING ORGANIZATION FOR PRODUCT DEVELOPMENT

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I retain the memory of whatever I see or learn in my vision for a long time, so that whatever I once see or hear I remember. And I see and hear and know at one and the same time; and in a flash that which I learn, I know. And what I do not see, I do not know, since I am not learned. And the things which I write, I see and hear in that vision, and I do not put down any other words than those I hear, and I offer whatever I hear in the vision in unpolished Latin, since I have not been taught to write in the vision as philosophers write.

Hildegard of Bingen, 1175
A QUICK BROWSE THROUGH THE THESIS

**Introduction**, the research questions, and the outline of the thesis are given in chapter 1 on page 1.

The evolution of the research questions and action research are explored in the **Research Methodology** chapter, see chapter 2 on page 11.

**An Engineering Management Model** that could be used to improve organizational learning in product development is presented in chapter 3 on page 35.

**In Phantom Turbine** development, development of technology and process for product development are combined with focus on future customer needs. Read more in chapter 4 on page 55.

**Process Improvement Simulations** are a method for simulating and comparing improvements to the development process before they actually take place. Read more in chapter 5 on page 79.

**Knowledge Overlapping Seminars** are a method for reducing misunderstandings between engineers. Read more in chapter 6 on page 101.
ABSTRACT

The costs of late changes due to earlier misunderstandings in product development are very high, even though no company wants to admit how high they really are. From experience in Swedish industry and based on results from previous research found in the literature, the conclusion is drawn that people need to talk to one another to be able to understand one another and thereby avoid misunderstandings. Information technology can be used to increase the frequency and amount of information communicated within a product development organization but it cannot replace talking. This project aims at delivering methods that are intended to improve effectiveness of product development, i.e. fewer misunderstandings will contribute to improved quality and, as a consequence, lowered costs and shortened lead-times.

The project also aims at delivering a method that is intended to improve organizational learning, which would in turn improve a company’s ability to adapt more easily to a changing environment. The ultimate goal and vision is more competitive companies.

The following contributions to the theory of Engineering Management are presented in this thesis: (i) ‘An Engineering Management Model for Improvement of Organizational Learning’ is a theoretical model of how three management disciplines can be used together to improve organizational learning within a product development organization, based on the framework of Senge’s five disciplines. (ii) ‘Phantom Turbine Development’ is a presentation of how people engaged in development of technology and processes for product development can share goals and visions based on future customer needs. (iii) ‘Process Improvement Simulations’ are a method for simulating and comparing improvements to the development process before they actually take place. (iv) ‘Knowledge Overlapping Seminars (KOS)’ are a communication method for engineers in a product development team with the purpose of eliminating misunderstandings. Obstacles that occur in ‘ordinary meetings’ are avoided in a KOS.

Action research has been used as research method. It has been performed at ABB STAL, a company developing gas and steam turbines, where the researcher of this project is employed. The approach used, collaborative action inquiry, is characterized by the researcher having an almost total identification with the activities and direction of change of the company, which is the case since the research is to a great extent based on the researcher’s own experience.
SAMMANFATTNING


Följande bidrag till forskningsområdet Metoder och organisation för ledning av ingenjörsarbete (Engineering Management på engelska) lämnas i denna avhandling: (i) En modell för ledning av ingenjörsarbete är en teoretisk modell av hur tre olika ledningsfilosofier kan användas tillsammans för att förbättra det organisatoriska lärandet inom en produktutvecklingsorganisation baserat på Senges ramverk ‘De fem disciplinerna’. (ii) Fantomturbintutveckling är en presentation av hur ingenjörer som arbetar med utveckling av teknik och process för produktutveckling kan dela mål och visioner baserade på framtida kundbehov. (iii) Simulering av processförbättringar är en metod för att simulera och jämföra förbättringar av en utvecklingsprocess innan de införs. (iv) Kunskapsöverlappningsseminarium (KOS) är en kommunikationsmetod som ingenjörer i ett produktutvecklingsteam kan använda för att eliminera missförstånd. Hinder som uppträder i vanliga möten undviks i KOS.

Aktionsforskning har använts som forskningsmetod. Forskningen har utförts på ABB STAL, ett företag som tillverkar gasturbiner och ångturbiner, där författaren till denna avhandling är anställd. Det använda angreppssättet, samverkande aktionsforskning, karaktäriseras av att forskaren i stort sett totalt identifierar sig med företagets aktiviteter och förändringsriktning, vilket väl överensstämmer med forskningen inom detta projekt som till stor del är baserat på författarens egna erfarenheter.
Acknowledgements

Not last nor least, but first and most of all I want to express my gratitude to my life companion, the mother of our two children, my wife, Eva. You made it possible for me to pursue this research project. Especially the writing of the thesis during the last five months has been a tremendous work effort for both of us. Without your support this thesis never would have seen the light of day. For what it is worth, I dedicate this thesis to you. I love you so very much.

A very sincere thank you also goes to my scientific advisor professor Bo Bergman at Chalmers University of Technology in Gothenburg. You opened my eyes to the academic world and had the courage and wisdom to let me follow my own conscience and commitment. This research project could have ended a long time ago if it was not for your support. I will cherish the memory of these three years for the rest of my life.

I also want to thank my other advisors, Hans-Lennart Olausson at ABB ALSTOM POWER (formerly ABB STAL) in Finspång, professor Margareta Norell at The Royal Institute of Technology in Stockholm, and professor emerita Gunnela Westlander. Thank you for reviewing my project and guiding me, each one with a different perspective, and hence improving the quality of the final thesis.

During my three years within the academic world I have been associated to the Division of Quality Technology and Management at Linköping University in Linköping. It is sad to leave you all now when I have finally spent some time at the department and made so many good friends. I thank you all, especially Lars Nilsson and Mattias Elg for reviewing my thesis thoroughly and Pia Blomstedt for always being there and making it all work. I promise to come and visit you all soon. Quality never goes out of style.

If I had not been employed at ABB STAL (now ABB ALSTOM POWER) in Finspång four years ago, this research project would never had happened. I want to thank everybody that participated in the project one way or another. You are too many to mention here but you know who you are. Even so, I want to put a special thank you to my managers during these years, Thomas Andersson, Mats Björkman, Hans-Lennart Olausson, and Per Thörnblad, for maybe not always knowing what I was talking about but always believing in me. Didn’t you? Now when I am back you will see more of me. That is a promise and a threat.
Much of my experience that I base this research project on was gained during 1984 through 1996 at SAAB in Linköping. It seems so distant now that the names of the people that I worked together with are beginning to fade away. Three people that I will never forget though are Knuth Sjöquist, Anders Lindberg, and Göran Rydholm. Thank you for making these years a happy, learning experience. Once a loads analysis engineer, always a loads analysis engineer.

Two of the chapters in this thesis are built on previous papers. I want to thank the co-authors of these papers.

The co-author of the paper ‘An Engineering Management Model For Learning Organizations’ was Ingrid Samuelsson at Chalmers University of Technology in Gothenburg. Thank you Ingrid for the very valuable discussions about the model. My initial ideas definitely needed to be structured. Once we had done that, we developed the model further to a tool for improving organizational learning in a product development organization, which was a major contribution to this thesis.

The co-authors of the paper ‘Process Improvement Simulations using the Work Transformation Model’ were Anna Öhrwall Rönnbäck at Linköping University in Linköping and Professor Steven Eppinger at MIT in Boston, USA. Thank you Anna for the fruitful discussions on the method and the improvements that you contributed to from the application at SAAB. Also, thank you Steve for valuable input and for guiding the research work for that paper.

During this research project I have also had some short but very valuable discussions with Professor Tom Allen and Professor Don Clausing, both at MIT in Boston, USA. Your input was very valuable. Thank you.

The use of proper English has been secured by Alan McLean. Thank you Alan.

Finally I want to send a big keep-up-the-good-work salute to all ENDREA graduate students in Sweden. I am sure ours will be an important network in Swedish industry in the future.

This work was financially supported jointly by ABB ALSTOM POWER and the Swedish Foundation for Strategic Research through the ENDREA research program. This support is gratefully acknowledged.
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CHAPTER 1
INTRODUCTION

The first chapter gives an introduction to the thesis. The problem addressed and the research area are identified, leading to the research questions. Furthermore, the theoretical contributions and the industrial relevance of the thesis are discussed. Finally, the outline of the thesis and previous work are presented.

1.1 COMMUNICATION IN PRODUCT DEVELOPMENT

1.1.1 Lost in space

In September 1999 NASA lost contact with the Mars Climate Orbiter when it crashed on the surface of Mars. Millions of dollars and thousands of hard-working man-hours lost in space; What had happened? Reports in the news said something about ‘technical problems’ which is usually the case when something does not work as it is supposed to. One starts to think ‘What kind of technical problems?’ and ‘How could that happen in such an advanced project?’. Surely, that is not what you should expect from a project where the best and the latest technologies of all types - especially information technology - are used throughout the complete project and especially in the product development organization that designed the spacecraft. Or should you?
Some time later one could read in the papers\(^1\) what had happened. It was *not* a technical problem. It was a *human problem* concerning communication on a technical matter; a simple misunderstanding between the engineers who designed the spacecraft. One team of engineers used US units (pounds) and another team used metric units (newtons) which resulted in the wrong correction for gravity by the navigation system, which ultimately led to the crash.

The spacecraft was developed according to NASA’s new ‘faster, better, and cheaper’ development process, but critics claimed that the chase for lower costs had led to lack of quality. Management at NASA dismissed the criticism and put the blame on poor conformance to specified work procedures. Heads had to roll.

The investments in information technology in product development organizations have been enormous in the last decade. The *amount* and *frequency* of communicated information within a product development project has exploded, which sometimes has led to information overload. On the other hand, the *content* and *context* of communicated information has not changed. It is still just information that can be misunderstood if not put into the right perspective.

Information - communicated in wires or wireless - is not enough. What has to be dealt with to improve understanding has many names; mental models (Senge, 1990), tacit knowledge (Nonaka, 1994), exformation (Nørretranders, 1993), or technical competence (Allen, 1977). Davenport and Prusak (1998) put it very simply: “Research shows time and again that a shared language is essential to productive knowledge transfer”.

People need to talk to one another to be able to understand one another. Engineers who use state-of-the-art software and hardware, but do not understand one another, can communicate information but they cannot share knowledge. Management who think that product development performance will be improved by investments in IT and more specified work procedures but at the same time do not recognize the importance of talking are ‘lost in space’.

The costs of late changes due to earlier misunderstandings are very high, even though no company wants to admit how high they really are - ask NASA.

\(^1\) See e.g. Svenska Dagbladet, 1999-11-28 or 
1.1.2 My experience

During my sixteen years in specialized engineering disciplines at SAAB and ABB STAL, I have seen many misunderstandings between engineers engaged in product development projects. Sometimes I was the only one to notice it since I happened to have some knowledge of what both of the engineers were talking about. They used the same words and did not notice any ‘conflict’ or misunderstanding, but when I heard what they said I realized that they did not mean the same thing. On some occasions I had to explain to engineers what they had agreed upon which led to some very surprised-looking faces. I am sure that there were many misunderstandings that I did not see or hear, which sooner or - more likely - later became evident.

This research project is founded on my experience from sixteen years of engineering work in product development organizations. I used to view the problem of misunderstandings between engineers as a ‘disease without a cure’. Three years of research within the academic world has taught me to ‘make a diagnosis’ of the problem. Before that I only knew the ‘symptoms’. Now I also know the ‘causes’ which I present in this thesis. Furthermore, a suggestion for a possible ‘cure’ for the problem, developed and tested in real applications in industry, is presented.

1.2 RESEARCH QUESTIONS

My starting point

I assume that the problem of misunderstandings within a product development organization has its origin in poor communication.

Starting point: Improved communication can improve the effectiveness of a product development organization.
My research area

Communication in product development is a very broad area of research. I focus on strategic and operational management of everyday engineering work, known as Engineering Management. It includes organization, cooperation processes, methods of communication, social psychology and work settings. It does not include engineering design theory and methodology or development of computerized communication tools.

Research area: Engineering Management.

My specific research questions:

First, I assume that an increased understanding between engineers with backgrounds in different areas of expertise, i.e. the creation of a common language, is important for improving effectiveness of product development. Hence, research question #1 is:

RQ1: How can understanding between engineers from different backgrounds in a product development organization be improved?

Second, since misunderstandings have a tendency to recur rather than result in changes I assume that a change in behaviour, i.e. organizational learning, is important to achieve a sustained improvement of product development effectiveness. Hence research question #2 is:

RQ2: How to improve organizational learning within a product development organization?

1.3 Theoretical Contribution

Four contributions to the theory of Engineering Management are presented in this thesis:

1. ‘An Engineering Management Model for Improvement of Organizational Learning’ is a theoretical model of how three management disciplines can be used together to improve organizational learning within a product development organization. Area of contribution: Learning Organizations.

2. ‘Phantom Turbine Development’ is a presentation of how people engaged in development of technology and processes for product development at ABB STAL share goals and visions based on future customer needs. Area of contribution: Integrated Product Development.
3. ‘Process Improvement Simulations’ are a method for simulating and comparing improvements to the development process before they actually take place. Area of contribution: Project and Process Management.

4. ‘Knowledge Overlapping Seminar (KOS)’ is a communication method for engineers in a product development team with the purpose of eliminating misunderstandings. Obstacles that occur in ‘ordinary meetings’ are avoided in a KOS. Area of contribution: Knowledge Management.

This research project has been conducted within the ENDREA graduate school. The focus within ENDREA is on industrially relevant research on product development. The focus in business schools is shifting from ‘production of knowledge as the pursuit of scientific truth’ to ‘production of knowledge from application’ (Gibbons, 1994; Huff, 1999). I classify the theoretical contributions mentioned above as knowledge from application.

Don Clausing wrote in his evaluation of ENDREA (Clausing, 1998): “Currently the projects are on important subjects and are well informed, but not especially bold. There is a tendency to stay close to the existing literature. It is certainly appropriate to know and summarize the existing literature on the topic being studied. The students need strong encouragement to then move beyond the literature to develop significant new insights and/or improvements to existing practice.” As I base my research on my own experience, I have tried to move beyond the literature and to develop new insights and improvements to existing practice, i.e. develop new knowledge from application. I leave it to the reader to judge the level of boldness.

1.4 INDUSTRIAL RELEVANCE

What is industrially relevant research on product development? Does it mean that this thesis should improve product development effectiveness? I do not think so. No thesis by itself improves product development effectiveness. The results presented in this thesis are meant to be deployed in industry, but also to be a brick in the building of new knowledge in future research on product development. Industrial deployment is discussed further in 7.3 ‘Deployment of methods’, p 128.

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The questions that I address in this thesis are fetched directly from industrial applications at SAAB and ABB STAL, where I have an industrial advisor. In that sense, the research is relevant to these two companies. From the feedback that I have gained from colleagues at other Swedish companies of similar size (relatively large companies) I conclude that the questions are industrially relevant and not only applicable to the two companies where I performed my research.

This project aims at delivering methods that are intended to improve effectiveness of product development, i.e. fewer misunderstandings will contribute to improved quality and, as a consequence, lowered costs and shortened lead-times. The project also aims at delivering a method that is intended to improve organizational learning, which would in turn improve a company’s ability to adapt more easily to a changing environment. The ultimate goal and vision is more competitive companies.

1.5 THESIS OUTLINE AND PREVIOUS WORK

1.5.1 Previous work

Previously published papers and the related chapters in this thesis are listed in table 1 on page 8. Furthermore, in figure 2 the relations are indicated by positioning the papers and chapters in the Engineering Management Model (presented in chapter 3).

1.5.2 Thesis Outline

The outline of the thesis is given in figure 1. The core of the thesis consists of chapters 3, 4, 5, and 6. In chapter 3 a theoretical model for Engineering Management is presented. It is suggested that the model could be used as a tool for improving organizational learning in a product development organization. In chapters 4, 5, and 6 ‘practical’ tools are presented that could help to implement the theoretical model in chapter 3. The tools in chapter 4, 5, and 6 could also be used separately to improve communication in product development.
1.5.3 Introductions to Thesis Chapters

Chapter 1 ‘Introduction’: The first chapter (i.e. this chapter) gives an introduction to the thesis. The problem addressed and the research area are identified, leading to the research questions. Furthermore, the theoretical contributions and the industrial relevance of the thesis are discussed. Finally, the outline of the thesis and previous work are presented.

Chapter 2 ‘Research Methodology’: In the second chapter I describe the background to my research work, i.e. my experience as an industrial engineer. First, I describe how the research questions have evolved during several years. Second, the methodology of qualitative action research is explored.

Chapter 3 ‘An Engineering Management Model for Improvement of Organizational Learning’: In this chapter a new theoretical model for engineering management is proposed. The purpose of the proposed model is that it should facilitate improvement of organizational
Figure 2   Relations between previous papers and chapters in this thesis.

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Table 1   Previously published papers and the related chapters in this thesis.
learning in a product development organization. The chapter is principally built on a working paper, co-written with Ingrid Samuelson at Chalmers University (Cronemyr and Samuelsson, 1999). Some of the material was first presented in a short paper at QERGO99 (Cronemyr, 1999).

**Chapter 4 ‘Phantom Turbine Development’**. In this chapter I present the concept of Phantom Turbine Development, as it was organized at ABB STAL in 1998 when I participated in the work in the process team for the complete development process. In Phantom Turbine Development, development of technology and process for product development are combined with common shared goals built on future customer needs.

**Chapter 5 ‘Process Improvement Simulations’**. In this chapter a new method for process improvement simulations is presented. I developed the method as an assignment in an ENDREA course on DSM held by professor Steven Eppinger and developed it further in an application at ABB STAL during 1997 and 1998. The chapter is mainly built on material from a forthcoming paper, co-written with Anna Öhrwall Rönnbäck at Linköping University, and Steven Eppinger at MIT (Cronemyr, Öhrwall Rönnbäck, and Eppinger, 2000). Some of the material was first presented in a short paper at ICED99 (Cronemyr, Öhrwall Rönnbäck, and Eppinger, 1999).

**Chapter 6 ‘Knowledge Overlapping Seminars’**. The experience leading to the research for this chapter started in 1984 when I started to gain experience with specialized engineering domains at my work at SAAB. Many years later, at ABB STAL in 1999, I had the possibility to scientifically and operationally design and test a new communication method for engineers in a product development team with the purpose of reducing misunderstandings. Prior to this thesis the results have only been published in interim reports.

**Chapter 7 ‘Conclusions of the thesis’**. In the last chapter I return to the research questions and draw the conclusions of the thesis. Also, further research and deployment of methods are discussed, before concluding the thesis with some final words.
CHAPTER 2
RESEARCH METHODOLOGY

In the second chapter I describe the background to my research work, i.e. my experience as an industrial engineer. First, I describe how the research questions have evolved during several years. Second, the methodology of qualitative action research is explored.

2.1 INTRODUCTION

In some theses that I have read, the research methodology used is not described at all. Some do describe a ‘normal science path’ from research question via research design and theoretical studies to validation of practical results, if any. Others describe a more complex research process where the research question grows and changes during the research project. Not following the ‘normal science path’ is somewhat controversial to some ‘scientists’ who have a very clear opinion about what is science and what is not. Since these scientists often are asked to review research projects, some researchers may feel forced to describe a fictitious research process that looks more like a ‘normal science path’ than is actually the case.

In my view a research process takes place where the mind is expanding as more knowledge is created. When empirical and theoretical knowledge are connected an abduction (Alvesson and Sköldberg, 1994) inspires to a changed research question along the way. If the opposite were true the research question would never change and no knowledge would have been created during the research project other than facts that can be viewed with the same view as one started with.
What I present here in my thesis - and share with the reader - is knowledge that I have gained along the way. I started with the feeling that ‘engineers do not understand one another’ and now some years later I am writing down what I found out along the way. Below I describe my way and how I found out that what I have been doing is called “action research”.

### 2.2 Birth and Evolution of the Research Questions from Empirical Experience

In this section, which is quite extensive, I will try to illuminate my path back and forth between empirical experience from the industrial world and theoretical knowledge from the academic world. My research questions, as described in section 1.2 ‘Research questions’ have evolved from combinations of experience from these two worlds.

#### 2.2.1 The early SAAB years - Gaining experience in engineering disciplines

In 1984, when I began working in the JAS39 Gripen multi-role fighter aircraft project at SAAB³ I did not know that one of my tasks would be to translate messages between engineers of different departments.

My position was as a loads analysis engineer at the Aeroelasticity and Loads Department. It was a small department, responsible for transforming - through a very complicated process - aerodynamic pressure distributions from wind-tunnel tests to critical load cases for sizing of the aircraft and its components. As a loads analysis engineer I had to have knowledge from many different disciplines, the two most important being aerodynamics and structure mechanics. I learned a lot from my colleagues - especially from my group manager - about these disciplines and also the specific knowledge of loads analysis that is located somewhere in between, but is not a part of, aerodynamics and structure mechanics.

Even though our small department was a very important link between the two big departments Aerodynamics and Structure Mechanics we were considered orphans and hence we were moved from one big department to the other at every re-organization. We were not considered real aerodynamics engineers, nor real structure mechanics engineers. We were loads engineers.

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It was clear that our job was not considered very important by some and it struck me how determined these people were to stick to their own departments and not to let anyone from outside in. People in the two departments had different mental models and completely different views on the common goal. In Aerodynamics the performance of the aircraft was the overall goal and in Structure Mechanics the strength and life of the aircraft were most important. Most people were not very interested in loads and aeroelasticity even though these disciplines connect aerodynamics to structure mechanics. At that time I thought people did not want to talk to one another. Now I think that they could not talk to one another. The two domains had different languages. I knew both languages pretty well and hence I sometimes became an interpreter and translator.

In parallel to working with loads analysis and development of new methods for that, I studied university courses during five years. Since there were no loads-analysis courses - it is not an academic discipline - I specialized in aerodynamics and structure mechanics, gaining deeper knowledge within these knowledge domains. The work for my Master’s thesis which was in aerodynamics was carried out at FMV-Prov, i.e. the flight test facility of the Swedish Defence Materiel Administration (Cronemyr, 1990).

2.2.2 The late SAAB years - Gaining experience in cross-disciplinary software and processes

After graduation I began working with development of ‘cross-disciplinary software’ for connecting loads analysis to flight test loads measurements (the responsibility of the Flight Test Department). It was quite successful in speeding up the process but it did not increase the knowledge about the other domains.

In 1992 and the years to follow I was managing a project called SALSA (Static Aeroelasticity in LoadS Analysis) which had the purpose of developing a cross-disciplinary software for the complete aircraft sizing process (in Swedish: ‘dimensioneringsprocessen’), starting with tasks in the Aerodynamics Department, flowing through the Loads Department to the Structure Mechanics Department. It was to be used in the development of the next version of the Gripen aircraft.

At that time Loads and Aeroelasticity had become a sub-department to the Structure Mechanics Department, consequently people at the Aerodynamics Department considered the SALSA project to be a structure mechanics project. It was very hard to get resources from Aerodynamics
to develop the aerodynamic modules. Finally, people from the Structure Mechanics Department had to develop those modules too.

In the original project specification, which I had written, the twofold goal of the project was stated, both to develop a cross-disciplinary software and to develop a new cooperation process for the departments involved. As project manager for SALSA I had the authority to do the first but not the second. In the first respect, the project was a success since we developed a complex program with many different functions in different modules, at the right time and almost within the specified budget. But since the project did not achieve a new cooperation process, the program was used to carry out tasks ‘the old way’ and the functions that were developed to support ‘cross-disciplinary’ tasks were not used.

During 1994 top management at SAAB introduced the ‘New product development process’ (Andersson, Backlund, Cronemyr, Pohl, Sveder, and Öhrwall Rönnbäck, 1998; Danilovic, 1998, 1999). From the beginning the product development process had been divided into five sub-processes: the airframe development process, the aeronautics development process and three more processes, one for each big department. After the failure to establish a common process view within Aerodynamics and Structure Mechanics I volunteered to participate in the process development team of the airframe development process. Already at the first meeting all members of our process development team protested against the division into sub-processes. We considered them to be departments rather than applied processes. We were told that these were the sub-processes and that we should concentrate on the airframe development process. Consequently, very little was accomplished even here to establish a common process view within Aerodynamics and Structure Mechanics. People at the Aerodynamics Department mapped the aeronautics development process and people of the Structure Mechanics Department, i.e. our team, mapped the airframe development process. The very important connections in the aircraft sizing process were indicated in the process map of the airframe development process but not ‘on the other side’.

2.2.3 The first year at ABB STAL - Gaining more experience in engineering disciplines

In the beginning of 1996, after more than eleven years at SAAB, I moved to ABB STAL in Finspång. My position was formally as a blade dynamics engineer at the Structure Mechanics Department.

Department but it was stated from the beginning that I should concentrate on the task of ‘narrowing’ the Aerodynamics and the Structure Mechanics departments to each other. The first year I concentrated on learning turbine technology and especially blade dynamics. I quickly identified a lack of common understanding of the cooperation process that is necessary to be able to work with aeroelasticity, a very important topic for the development of high performance blades.

Many things were the same at SAAB and at ABB STAL, e.g. the lack of a common view on the process and the very specialized knowledge domains that prevented engineers from understanding one another. Not everything was the same though. After some time of adaptation to the new company culture, I realized that the people at ABB STAL really wanted and tried to cooperate across the border between Aerodynamics and Structure Mechanics. That was very unusual at SAAB. On the other hand, aeroelasticity was a department of its own at SAAB. At ABB STAL it was not the responsibility of only one department. Blade dynamics, i.e. the mechanical side of aeroelasticity, was the responsibility of the Structure Mechanics Department but no-one was very interested in unsteady aerodynamics, i.e. the aerodynamic side of aeroelasticity. Actually, at SAAB unsteady aerodynamics was the responsibility of the Aeroelasticity Department, not the Aerodynamics Department.

2.2.4 Entering ENDREA as an industrial researcher - Discovering the academic world

In November 1996 I saw an advertisement for a new Swedish graduate school called ENDREA (Engineering Design Research and Education Agenda). The focus within ENDREA was on industrially relevant research on ‘Holistic Product Development’ combining the three research disciplines ‘Design Theory and Methodology (DTM)’, ‘Simulation and Digital Prototyping (SDP)’, and ‘Engineering Management (EM)’. I knew right away that this was definitely something for me. The manager of the R&D department, Hans-Lennart Olausson, who also was the owner of the development process and later became my industrial advisor, approved that I should apply as a half-time industrial researcher and that I should continue to work with process development at ABB STAL the remaining half-time. The plan was to deliver a licentiate thesis after four years of half-time research.

In my application I attached a proposal for a research project with the (not very short) title: ‘Re-engineering the development process by using state of the art software and engineering
management, emphasizing on the interaction between design, structural mechanics and fluid dynamics’. It dealt with process management and parametric CAD/CAE models. In the first interview I got the questions “What is your research question?” and “What will be your scientific contribution?”. I had never thought about that so it was very easy to answer these two questions. “I don’t know”. Even though I had a feeling inside me that ‘engineers do not understand one another, I want to do something about it’, at that moment I could not express it.

I was accepted to ENDREA in Linköping and was - after some time - appointed a main advisor. I did not know who could accept me and my experientially based research project but it turned out very well when I got professor Bo Bergman of Quality Technology and Management as my research advisor. That was a major step forward for me as a researcher. Now I know that he was a little bit unsure of my research project in the beginning. Who would not have been?

In my ‘research half-time’ I started to attend courses in Integrated Product Development and Design Structure Matrix. In my first official project description the title had shrunk somewhat to ‘Success criteria for the introduction of concurrent engineering software in the development process’.

2.2.5 The first ABB STAL / ENDREA years - The confusion of the two worlds

From the end of 1996 until the beginning of 1998 I participated in a project within the ongoing process orientation work at ABB STAL. It was a process development project with the aim of mapping and suggesting improvements to the blade development process. This was very encouraging because engineers from several disciplines were among the participants: aerodynamics, blade dynamics, stress, mechanical design and - later - cooling and manufacturing. The process of making the process map was very valuable to improve the common ‘holistic’ view on the activities that were carried out at the different departments. We learned a lot about how tasks interrelate even though the map is not very nice to look at for somebody who did not participate (see figure 39 on page 94). The map easily became very detailed but we found out that “details are necessary but don’t get stuck in details”.

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The method for process improvement simulations given in chapter 5 ‘Process Improvement Simulations’ was developed as an assignment in the Design Structure Matrix course given by Professor Steven Eppinger from MIT. The method was developed in cooperation with the blade development process team and the method was used to prioritize and select improvements to the mapped process.

Based on my experience at SAAB and at ABB STAL, in the end of 1997 I identified three major pre-requisites of the development organization necessary for establishing an ability to work with cross-disciplinary matters like aeroelasticity. Later I found, in discussions with people at other departments and in other organizations, that these do apply in many situations, not only in the case of aeroelasticity. The three pre-requisites were:

- **Common tools and data** for different engineering disciplines,
- **A common view on the development process**, and
- **A common language** built on shared knowledge, i.e. knowledge overlapping between engineering disciplines.

The three items above are listed in the chronological order as I found them. By the time I entered ENDREA I had found the first two items, which is evident in the early titles of my project. By the end of 1997 the title of my project had become ‘Opening up closed engineering domains’ (which continued to be the title for two years until the end of 1999). In the first year of academic studies I had found that many researchers had written about the first two items but I had found very little written about the thing that I had just recognized, i.e. the third item above. By then my research question was ‘How to achieve knowledge overlapping?’ I tried to describe the reason for my research question as “engineers from different disciplines think they understand one another but they do not”. That is not the way you should express yourself in the academic world, which led to reactions from scientists who claimed that I had to “prove it!” I thought that my experiences were of no scientific relevance. Luckily for me, both my advisors saw that I believed in what I was talking about and gave me valuable guidance on how to proceed, Bo in a scientific way and Hans-Lennart in an industrial way. Now I realize that “engineers do not understand one another” is easily misunderstood as if I meant that they never understand one another. Of course they do, but sometimes they do not - without knowing it.
2.2.6 The following ABB STAL / ENDREA years - Applying, increasing, and connecting experience in ‘the real world’ to academic knowledge and back.

In 1998 I was deeply involved in a project at ABB STAL called P2000. Since the project of mapping and re-engineering the blade development process had turned out a success in terms of integration and creation of a common view on the blade development process, several process development groups were created for sub-processes to the gas turbine development process. These were e.g. the cooled turbine blade development process (our group had dealt with development of uncooled turbine blades and compressor blades), the rotor and disk development process, the combustor development process, the mechanical systems development process, and the electrical and control systems development process. Together with some groups that were to develop a ‘tool box’, specify project management principles etc. the aim was on a new product development process called P2000. My task was to coordinate and help the process development groups. I was appointed process developer in the process team for the complete development process. I worked directly under the R&D manager, likewise the owner of the development process. It was in this process team that the Phantom Turbine project was created, as described in chapter 4 ‘Phantom Turbine Development’. I did not invent it, I learned it from working with it and made some contributions to it. What I realized later was that the concept of the Phantom Turbine was something new since it combined technology development and process development.

During 1998 I attended several courses, e.g. in research methodology, and at the same time I was very busy with process development in the P2000 project. The planned half-time plus half-time in reality became full-time plus full-time which was more than I was up to. I felt that I could not concentrate on anything. I was always busy with ‘emergency calls’. I did not have any time to think and reflect on my research project. During the summer vacation I suddenly had the time to sit down and think, read, and write. It was in the book ‘Managing the Flow of Technology’ by Tom Allen (1977) that I for the first time found ‘proof’ for my experiences. I combined that new knowledge with my experiences and all of a sudden I had invented an embryo that, during the next year, would develop into a method for engineers to share domain-specific knowledge. The method is presented in chapter 6 ‘Knowledge Overlapping Seminars’.

Finally, at the end of 1998, my advisors and I agreed that I should concentrate on the research task for one more year on full-time instead of two more years on half-time.
2.2.7 The final ENDREA year - Concentrating on theoretical development and action research

In the first half of 1999 I attended a course in Systems Engineering, held in Linköping. Among the lecturers was Professor Don Clausing, the author of the book ‘Total Quality Development’ (Clausing, 1994). In one of the seminars I presented the Phantom Turbine development at ABB STAL as a contrast to Clausing’s well-known ‘technology stream’. I was surprised that it was very well received and considered to be something new. I started to think that maybe I should write a paper about it. I did not find the time to do so but it turned out to be a chapter in this thesis (see chapter 4).

In the spring I had studied more on Knowledge Management, e.g. Allen (1977), Robertson and Allen (1992, 1993), Nonaka (1994), Nonaka and Takeuchi (1995), and Davenport and Prusak (1998). My idea of the Knowledge Overlapping Seminar (KOS) was well developed and ready to try out in a real application. I had also developed an analysis model, with surveys and interviews, as an assignment in the course Organizational Management and Work Psychology, to be used when evaluating the effects of KOS. Unfortunately the first actual application of KOS in a gas turbine development team at ABB STAL was delayed for almost half a year due to a major re-organization at ABB STAL when most departments had got new managers. It was no longer only my industrial advisor that had to approve my allocating time in a gas turbine development project. Discussions with new, and initially less interested, managers took several months. Finally, after the summer of 1999, I had the opportunity to actually test the method that I had invented that should help engineers to talk to one another in a new way. As can be seen in chapter 6 it was a success for the gas turbine project. For me as an engineer on a mission, it was an enormous success.

During the summer I presented the method for process improvement simulations on two occasions, in August at the ICED conference in Munich (Cronemyr, Öhrwall Rönnbäck, and Eppinger, 1999) and in September at a DSM workshop in Boston. Even though many people found it interesting I still did not think that it was my major research task. On several occasions I got the ‘advice’ to write a couple of papers about the method and my licentiate thesis would be complete. “Well” I replied, “I am more interested in how engineers speak to one another”. I was told that, that is not the easy way to accomplish a thesis. I know.
In parallel to all these activities I also attended meetings in several networks, one of them being the network for Integrated Product Development, supervised by Margareta Norell, professor of Integrated Product Development at KTH, the Royal Institute of Technology in Stockholm. It was at one of these meetings that everything fell into place, although I did not realize it until some days later. I had thought of knowledge overlapping (what Nonaka calls redundancy, see chapter 6) for some time and the network meeting was allocated entirely to a discussion on how to create knowledge overlapping. I started the meeting with a presentation of my view on knowledge overlapping (see figure 7 on page 41 and figure 10 on page 45). The other participants of the meeting, a mix of researchers and industrial executives, thought that my ‘deep’ view on overlapping was interesting and important but also stressed that a ‘helicopter’ view was equally important, meaning a common process view (see figure 9 on page 43). I totally agreed upon the importance of a common process view but emphasized that a process view was an abstract view on how concrete tasks were related while what I was talking about dealt with the connection of superficial knowledge of different domains through common profound knowledge. It was when, some days later, I drew the figures on top of each other that I created the model in figure 11 on page 46 and realized that all my three items, i.e. the three necessary pre-requisites for cross-disciplinary work in a product development organization, could be identified as engineering management principles in the model. At that meeting the engineering management model in chapter 3 was created. Furthermore, the three methods described in chapter 4, chapter 5, and chapter 6 could be located in the model with ‘one arrow each’. A very preliminary version of the model was presented in June at the QERGO conference in Linköping (Cronemyr, 1999).

In the end of 1999 one more important event took place. I attended my last postgraduate course (i.e. before the licentiate thesis) called Total Quality Management in Learning Organizations held by my advisor Bo Bergman, now SKF Professor in Total Quality Management at CTH, Chalmers University of Technology in Gothenburg. I had many experiences of the difficulties of achieving ‘organizational learning’, i.e. an organization’s ability to learn from experience and change behaviour accordingly. Now I got deeper down into the academic knowledge of learning organizations and realized that I had actually already worked a lot in this area. A fellow ENDREA research student, Ingrid Samuelsson at CTH, and I developed the engineering management model further and identified Senge’s five disciplines of a learning organization (Senge, 1990) in the model. Hence we called it ‘An Engineering Management Model for Learning Organizations’. In a working paper (Cronemyr and Samuelsson, 1999) we proposed
that the engineering management model could be used as a tool for improving organizational learning within a product development organization. Chapter 3 ‘An Engineering Management Model for Improvement of Organizational Learning’ in this thesis is principally built on that working paper.

2.2.8 Finally - The thesis and the research questions

As I have described, the research questions and the project title have changed and evolved along the way but the central commitment from the beginning has not changed, i.e. ‘engineers do not understand one another, I want to do something about it’. Now, in the beginning of 2000, my project is called ‘Towards a learning organization for product development’ and the research questions of the thesis are: ‘How can understanding between engineers from different backgrounds in a product development organization be improved?’ and ‘How to improve organizational learning within a product development organization?’.

If I would have been controlled to follow a ‘normal science path’ this evolution would not have been possible. As I have indicated, some have tried to steer me in such a direction but with the support of my advisors I followed my own conscience and commitment. I am glad I did.

2.3 ACTION RESEARCH

If it is not ‘normal science’, what is it? For me as an engineer with a technical education, it was a relief to find out that my research methodology is not ‘non-scientific’. It is a methodology with a long tradition called action research.

2.3.1 To help the practitioner in an action of planned change

‘Action research’ was first introduced in social research by John Collier in 1945 (Collier, 1945). The psychologist Kurt Lewin, by many considered to be the father of action research, argued for a research discipline with the main purpose “to help the practitioner” (Lewin, 1946). According to Lewin, action research is a parallel action and knowledge base creation for the researcher when he/she participates in an action of planned change in cooperation with the client/practitioner. He also had the opinion that the researcher could accept the following tasks: consulting of different alternatives of action, evaluation, conducting experiments, independently performed research in a perspective of gaining long-term knowledge. Lewin described the steps of research in an ‘action of planned change’ as planning, fact-finding, and
execution (see figure 3). Blake and Mouton (1984) describe action research as an example of a catalytic intervention characterized by “In intervention, a catalytic consultant is the agent. He or she enters a situation with the intention of increasing the rate at which a process of change is occurring. The goal is to assist those within the status quo to do what they are doing in an improved way.” (Blake and Mouton, 1984, p.288) Blake and Mouton identify the importance of the consultant, i.e. the researcher, “accepting [the client’s] felt needs. The underlying real problems [...] are then likely to come to the surface and can be dealt with as they become evident.” (Blake and Mouton, 1984, p.290)

Elden and Chisholm (1993) compare ‘normal science’ to ‘classical action research’ and ‘advanced action research’. Briefly, these disciplines can be described as ‘experiments with clear definitions and concepts’, ‘analysis of a closed system’, and ‘analysis of a system open to anything’ respectively. Gunnla Westlander (1999:a) has compiled two comparisons by Elder and Chisholm (Elder and Chisholm, 1993; Chisholm and Elder, 1993). A compressed version of that compilation is given in table 2. The type of action research that I have carried out mostly resembles advanced action research but also has some similarities to classical action research (see * marks in table 2).
<table>
<thead>
<tr>
<th>Main features</th>
<th>Normal science</th>
<th>Classical action research</th>
<th>Advanced action research</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main purpose</strong></td>
<td>Laboratory experiment as model</td>
<td>Solving practical problems <strong>and</strong> contributing to general theory. <strong>also:</strong> Making change and learning a self-generating and self-maintaining process. *</td>
<td></td>
</tr>
<tr>
<td><strong>Research design</strong></td>
<td>Experimental design. Researcher is sole creator of the study.</td>
<td>A laboratory-like experiment in natural environment. Local knowledge contributes to general theory.</td>
<td>Participatory approach: people who supply the data become full partners or co-researchers. *</td>
</tr>
<tr>
<td><strong>Purposes and value choice</strong></td>
<td>Theory-building, abstract modeling, produce representational knowledge.</td>
<td>Important issues are <strong>what</strong> is studied, <strong>how, who</strong> makes sense of data, <strong>who learns.</strong> <strong>also:</strong> The capacity of the system is being studied. Emphasis on possibility rather than on prediction. *</td>
<td></td>
</tr>
<tr>
<td><strong>Contextual focus</strong></td>
<td>Context-independent design. Sharp separation between theory and practice.</td>
<td>Context-bound inquiry. Problem definition grounded in the participants definition of the context, - multidisciplinary, prospective approach.</td>
<td><strong>also:</strong> Contextual focus is more complex, participant-grounded over a longer time frame. *</td>
</tr>
<tr>
<td><strong>Change-based data and sense-making</strong></td>
<td>NA</td>
<td>Data needed to track the consequences of intended changes; systematic data collection.</td>
<td>Ordinary members can generate valid knowledge as partners in a systematic empirical inquiry. Insiders’ own cognitive map or local theory as legitimate as the scientist’s. *</td>
</tr>
<tr>
<td><strong>Participation in the research process</strong></td>
<td>Subjects do not participate in having an influence on the process.</td>
<td>Participants produce important data. Researchers need the insider’s help to understand context and culture, *</td>
<td><strong>also:</strong> Participants play a much more central, generative role.</td>
</tr>
<tr>
<td><strong>Knowledge diffusion</strong></td>
<td>Traditional scientific publications.</td>
<td>Beliefs that a good solution will spread automatically. Researchers identify learning effects at a final stage. *</td>
<td>All participants diffuse experience to a much wider audience and field of potential application.</td>
</tr>
<tr>
<td><strong>Study object</strong></td>
<td>NA</td>
<td>Single production or company level *</td>
<td>Company, community, country.</td>
</tr>
</tbody>
</table>

*Table 2 Comparison of normal science, classical action research, and advanced action research. Compressed version of compilation in Westlander (1999:a), based on Elder and Chisholm (1993), and Chisholm and Elder (1993). (* identifies my project)*
2.3.2 The dual roles of researcher and client for an industrial researcher

Westlander (1998) compiles six different action research approaches. The approach that I have been using is the ‘collaborative action inquiry’. It is characterized by “The researcher has an almost total identification with the activities and direction of change of the client/company”. That is very true for me, which led to a confusion of roles. When am I a scientist/researcher/consultant, i.e. an outsider, and when am I the practitioner/client, i.e. an insider? As can be seen in table 2, that is an important question for a researcher on a ‘normal science path’ but since insiders and outsiders cooperate in action research, it is not equally important for me when doing action research. I am content with accepting that I am both.

A more relevant question is: When am I a consultant and when am I a researcher? Westlander (1999:a) deals with this question (translated from Swedish): “In action research, the researcher role and the consultant role are two different things. [...] In the consultant role the consultant can devote himself/herself to the helping function and to the client’s needs, and if useful research results are available these are used. In the researcher role the researcher has to carry out a double task and a not very easy adjustment, to satisfy the client’s needs and at the same time deliver new, and if possible, generalizable results to the body of change research.” Westlander concludes “It is not surprising that the methodological discussion on the value of action research is periodically recurring.”

What I have to deal with is the so-called goal dilemma for an action researcher. Simplified, the goal dilemma can be described as the conflict between the constraints for the purely research-minded researcher and the purely service-minded researcher, see table 3. On that scale

<table>
<thead>
<tr>
<th>The purely research-minded researcher</th>
<th>versus</th>
<th>The purely service-minded researcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collects data of insignificant usability for the client but of great scientific value,</td>
<td>versus</td>
<td>Collects data of great practical value for the client but of insignificant scientific value.</td>
</tr>
<tr>
<td>The great consumption of time needed for a scientifically well-founded analysis before a measure can be decided upon.</td>
<td>versus</td>
<td>The scarce time available for delivering a reasonably well-founded practical solution.</td>
</tr>
</tbody>
</table>

Table 3 The goal dilemma for an action researcher (from Westlander, 1999:a).
I can establish that I have been ‘on both sides’ on different occasions. I have performed my research project at ABB STAL for three years - 15 years if you count the years since I began at SAAB - but each intervention has taken approximately one to six months. The scientific conclusions are given - most of them for the first time - in this thesis but each intervention has also resulted in measures taken. It is my luck that I have had the permission and task to work like this.

### 2.4 EVALUATION OF QUALITATIVE RESEARCH

The results from my research, especially Knowledge Overlapping Seminars (see chapter 6), are based on evaluations of qualitative research. In this section I will discuss some aspects of the evaluation model used and the methodology of qualitative data collection.

#### 2.4.1 Evaluation model

As seen in table 2 the evaluation model used in action research is ‘performance evaluation’ unlike in normal science where ‘system evaluation’ is used. The differences and similarities between the two are given in figure 4 and in table 4. To a researcher performing normal science it is a matter of course to have a control unit (see B in figure 4) with which to compare results. In action research always taking place in a natural field setting it is not possible to find two settings with exactly the same pre-conditions, contexts, and environments. In the performance evaluation the performance effects are evaluated against the targets by use of quantitative output variables. These quantitative output variables are derived from qualitative data collection.

![Figure 4 System evaluation vs. performance evaluation.](image-url)
Have the expected outputs been achieved? What are the best conditions for accomplishing....?

Performance targets been reached?

<table>
<thead>
<tr>
<th>Evaluation model</th>
<th>Questions asked in the model</th>
<th>Evaluation results</th>
<th>There is consensus on...</th>
</tr>
</thead>
<tbody>
<tr>
<td>System evaluation</td>
<td>Have the expected outputs been achieved? What are the best conditions for accomplishing....?</td>
<td>Information on some specific (final) effect.</td>
<td>Objective (target); Means-end relationship; Quantitative variables.</td>
</tr>
<tr>
<td>Performance evaluation</td>
<td>Have the performance targets been reached?</td>
<td>Information on some specific (final) effect.</td>
<td>Performance effects; Quantitative output variables.</td>
</tr>
</tbody>
</table>

Table 4  Comparison between two evaluation models (excerpts from Westlander, 1986).

+ Consensus between client and researcher.

<table>
<thead>
<tr>
<th>Type</th>
<th>Study method</th>
<th>Role of the interviewee</th>
<th>Role of the interviewer</th>
<th>Interview aids</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Unstructured personal interview</td>
<td>Decides what shall be discussed and to what extent.</td>
<td>Wants to investigate the individual’s own view of the existential situation.</td>
<td>Notes taken freely during/after the interview, possibly following a predetermined frame; tape-recording if permitted by interviewee.</td>
</tr>
<tr>
<td>B *</td>
<td>Semi-structured personal interview</td>
<td>Has the freedom to specify what shall be taken up within the frame of each topic (conversation theme).</td>
<td>Wants to investigate the individual’s own view of conditions within each subject area.</td>
<td>Interview guide + notes taken freely during/after the interview; tape-recording if permitted by interviewee.</td>
</tr>
<tr>
<td>C</td>
<td>Structured interview (conversation led in detail by interviewer)</td>
<td>Tied to the questions posed by the interviewer.</td>
<td>Wants to assess and compare responses of a number of specific questions set up in advance.</td>
<td>Interview form</td>
</tr>
<tr>
<td>D *</td>
<td>Printed questionnaire (that may follow the pattern of either B or C, but normally type C)</td>
<td>Tied to the questions posed by the interviewer.</td>
<td>Wants to assess and compare responses of a number of specific questions set up in advance.</td>
<td>Questionnaire</td>
</tr>
</tbody>
</table>

Table 5  Types of question-asking (from Westlander, 2000). (* types used in my project)
2.4.2 Qualitative data collection

Four types of ‘questioning’, compiled in Westlander (2000), are given in table 5. In the case of Knowledge Overlapping Seminars I used questionnaires (type D) and semi-structured personal interviews (type B). The questionnaires are given in appendices 3 - 4 and the interviews are given in appendix 5. The results are given in section 6.3.4 ‘Results from analyses of all questionnaires and semi-structured interviews’, p 119.

Requirements on the questions in a questionnaire are given in table 6. The marks “*” indicate the types of information that I have collected.

<table>
<thead>
<tr>
<th>Data category</th>
<th>Data type</th>
<th>Example</th>
<th>Suitable for questionnaire alone?</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Factual information</td>
<td>a. constant over time *</td>
<td>year of birth</td>
<td>yes, indeed</td>
</tr>
<tr>
<td></td>
<td>b. varies over time *</td>
<td>age</td>
<td>yes</td>
</tr>
<tr>
<td>B. Data that are psychological by nature</td>
<td>c. evaluations (subject’s estimates of, for instance, employees in the company) *</td>
<td>interviewee’s reports on number</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>d. opinions *</td>
<td>interviewee’s opinion on the efficiency of, for instance, workmates</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td>e. attitudes</td>
<td>interviewee’s satisfaction with efficiency of, for instance, workmates</td>
<td>should be used with precaution</td>
</tr>
<tr>
<td></td>
<td>f. states of mind (mental moods)</td>
<td>depression, well-being</td>
<td>should be used with utterly precaution</td>
</tr>
</tbody>
</table>

Table 6  Different types of information that vary in terms of suitability for collection using questionnaire alone. (from Westlander, 2000). (* types that I have used in questionnaires)
At the beginning of each semi-structured interview five questions on a paper were shown to the interviewee, who then could speak freely on these questions, not necessarily in the order they were written on the paper. I repeated and summarized what the interviewee had said and if he agreed that that was in fact what he had said and meant, I put it down in writing under the corresponding question. After the interviews, similar answers were grouped together.

2.4.3 Relations between reality, data, and theory

Starrin et. al. (1991) present ideas about the relations between reality, data, and theory, when conducting qualitative research (see figure 5). They emphasize data collection and theory founding. Another important relation, added by me in the figure, is prediction. The way from reality via data to theory is a so-called grounded method (see e.g. ‘Grounded theory’ in Glaser and Strauss, 1967). Going all the way around, several laps, is called abduction (Alvesson and Sköldberg, 1994). It is also characteristic of ‘the research task’ (in contrast to ‘the consultant task’) when conducting action research.

As described in section 2.2 ‘Birth and evolution of the research questions from empirical experience’, I have collected much experience, during my years in industry. It took many years before I started to think in terms of data and about theory. When I started to ‘invent’ new

![Figure 5](image)

Figure 5 Relations between reality, data, and theory when conducting qualitative research (adapted from Starrin et al, 1991). + my addition.
theories from my data, some people told me that it was not scientific. I judge that to be a combination of lack of understanding of the essence of research methodology from the critical persons and a lack of knowledge about scientific discourse from myself. As I gained more experienced in academic theories and methodologies, I started to test existing theories on my data. I.e., could a certain theory predict the phenomena that I had seen in reality? Then new, or rather new combinations of, theories evolved. Finally these were tested in real applications - Knowledge Overlapping Seminars. Did the theory fit the data, and not the other way around. I did not know at that time - but now I know - that I followed the demands on the relation between theory and data, stated by Glaser (1978). These are:

- The theory has to fit the data, and not the other way around.
- The theory must work.
- The theory must have practical relevance.
- It must be possible to modify the theory when data is changing.

When going from data to theory one has to be sensitive to the data and should avoid filtering it through pre-made assumptions. The most important link between the data and theory is the coding and classification of the collected data (Starrin et. al., 1991). The method applied in this project was to code the printed interviews according to a coding key and to group similar answers together. They were not filtered in any way, except for the choice of questions.

### 2.4.4 Qualitative research and the criticism

When the qualitative research interview (QRI) was presented by Steinar Kvale in 1983 (Kvale, 1983) as a scientific method for conducting interviews it was criticized by ‘scientists’ for not being scientific. Kvale (1994) presented the most common objections to qualitative interviews representative for the ‘normal science’ view, see table 7. Since action research is qualitative by nature, the critique of action research corresponds very well to the objections which Kvale presents. I find Kvale’s counter-questions very relevant but I do not intend to - and cannot - answer them.
By explaining how my research project was conducted, which I do in this chapter, it is my intention that the reader shall be able to form his or her own opinion of the credibility of the study.

The credibility of a study, in terms of its validity and reliability, is as important for qualitative research as it is for quantitative research. By internal validity is normally meant to what extent the chosen work method is appropriate for the problem studied whereas by external validity is meant to what extent the results are generalizable to other areas. Reliability normally measures whether the instruments are of good quality or not and to what extent the results rely on a firm empirical foundation.

<table>
<thead>
<tr>
<th>Standard objection, the QRI...</th>
<th>Kvale’s counterquestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>...is not scientific, but only common sense.</td>
<td>What is science?</td>
</tr>
<tr>
<td>...is not objective but subjective.</td>
<td>How do you define objectivity? or, do you have an objective definition of objectivity?</td>
</tr>
<tr>
<td>...is not trustworthy, but biased.</td>
<td>If you cannot trust the results of an interview, how can you trust the results of our conversation?</td>
</tr>
<tr>
<td>...is not reliable, but rests upon leading questions.</td>
<td>Are the answers to leading questions not reliable?</td>
</tr>
<tr>
<td>...implies interpretations of interviews that are not intersubjective; different interpreters find different meanings.</td>
<td>Is there anything wrong in finding different meanings?</td>
</tr>
<tr>
<td>...is not a formalized method; it is too person-dependent.</td>
<td>Is it the wrong way to go through a non-formalized operational procedure?</td>
</tr>
<tr>
<td>...is not scientific hypothesis testing; it is only explorative.</td>
<td>Do you not find exploratory, descriptive studies in their own right to be an important part of science?</td>
</tr>
<tr>
<td>...is not quantitative, only qualitative.</td>
<td>Is mature science necessarily based on quantified observations?</td>
</tr>
<tr>
<td>...is not yielding generalizable results; there are too few subjects.</td>
<td>Why generalize?</td>
</tr>
<tr>
<td>...is not valid, but rests on subjective impressions.</td>
<td>What kind of validity does the interview not live up to?</td>
</tr>
</tbody>
</table>

Table 7 The ten standard objections to the qualitative research interview (QRI) suggested by Kvale (1994) and combined with corresponding counter-questions.

### 2.5 VALIDITY AND RELIABILITY

By explaining how my research project was conducted, which I do in this chapter, it is my intention that the reader shall be able to form his or her own opinion of the credibility of the study.

The credibility of a study, in terms of its validity and reliability, is as important for qualitative research as it is for quantitative research. By internal validity is normally meant to what extent the chosen work method is appropriate for the problem studied whereas by external validity is meant to what extent the results are generalizable to other areas. Reliability normally measures whether the instruments are of good quality or not and to what extent the results rely on a firm empirical foundation.
Lincoln and Guba (Lincoln and Guba, 1985, in: Merriam 1988) argue that qualitative research should put other values on the words validity and reliability. They suggest the use of ‘truth value’ for internal validity, ‘transferability’ for external validity, and ‘consistency’ for reliability.

Merriam (1988) describes *internal validity* as to what extent results correspond to reality. But due to three facts the researcher must judge the internal validity from the researcher’s own experiences instead of from reality itself, which we cannot experience directly. These facts are:

- Data do not speak for themselves. There is always an interpreter.
- A phenomenon cannot be measured or observed without changing it.
- Numbers and equations are abstract concepts. They are only representations of reality, not reality itself.

Merriam concludes that what is *considered to be true* by the persons in the studied situation can be more important than what *actually is true*.

Merriam proposes six techniques that can be used to ensure internal validity, see table 8.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description by Merriam</th>
<th>Usage in my project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangulation</td>
<td>Use of more researchers or more information sources.</td>
<td>Not used.</td>
</tr>
<tr>
<td>Member checks</td>
<td>Taking data and interpretations back to the persons interviewed.</td>
<td>Used.</td>
</tr>
<tr>
<td>Long-term observations</td>
<td>Repeated observations of the phenomenon at the research site during a long time.</td>
<td>Used</td>
</tr>
<tr>
<td>Peer examination</td>
<td>Asking colleagues to comment on the findings as they emerge.</td>
<td>Used.</td>
</tr>
<tr>
<td>Participatory modes of research</td>
<td>The studied persons participate in the research design.</td>
<td>Used.</td>
</tr>
<tr>
<td>Researcher’s biases</td>
<td>Clarifying the researcher’s assumptions and theoretical orientation.</td>
<td>Used.</td>
</tr>
</tbody>
</table>

*Table 8  Techniques for ensuring internal validity. (Adapted from Merriam, 1988)*
"External validity" is to what extent the results from a study can be applied to other (similar) situations, i.e. a question of generalizability. This is often a difficult question for qualitative as well as quantitative research. Merriam proposes two techniques for ensuring external validity, see table 9.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description by Merriam</th>
<th>Usage in my project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Similar studies</td>
<td>Cross-analysis of similar studies</td>
<td>Not used.</td>
</tr>
<tr>
<td>Reader or user generalizability</td>
<td>Leaving the extent to which a study’s findings apply to other situations up to the people in those situations.</td>
<td>Used.</td>
</tr>
</tbody>
</table>

*Table 9 Techniques for ensuring external validity. (Adapted from Merriam, 1988)*

"Reliability" means to what extent the results from a research project are consistent with reality. Due to the fact that human systems are never static and that the researcher is a part of the context in the studies, reliability is often a problem for qualitative research within social science. Merriam proposes three techniques for ensuring reliability, see table 10.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description by Merriam</th>
<th>Usage in my project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigator’s position</td>
<td>Clarifying the researcher’s assumptions and theoretical orientation.</td>
<td>Used.</td>
</tr>
<tr>
<td>Triangulation</td>
<td>Use of more researchers or more information sources.</td>
<td>Not used.</td>
</tr>
<tr>
<td>Audit trail</td>
<td>The researcher gives a thorough description of the design of the study. Then another researcher replicates the study.</td>
<td>Not used.</td>
</tr>
</tbody>
</table>

*Table 10 Techniques for ensuring reliability. (Adapted from Merriam, 1988)*


2.6 HOW TO WRITE A THESIS

I have not attended a course on how to write a thesis, but I have studied some literature on the subject. A good guide, published on the internet, is “How to Write a PhD Thesis” by Joe Wolfe (Wolfe, 2000). In addition to describing the normal disposition of a thesis, Wolfe gives some practical advice on how to write as well as how to live and behave during the writing period.

In general, the chapters in my thesis follow the normal disposition of a thesis. As I have mentioned several times, I did not follow a normal science path. I continued to go back and forth even during the writing of the thesis. I wrote the chapters in the following order: 5-3-6-2-4-1-7.

As for the language, I use the active voice and first person, “I asked the team members...”, instead of the passive voice, “The team members were asked...” or third person, “The author asked the team members...”. Some consider passive voice and/or third person to be more ‘serious’ but I do not agree. Wolf writes: “The active voice is simpler, and it makes clear what you did and what was done by others. Unless you are schizophrenic or a monarch, use the first person singular, not plural. As far as I know, the arguments for passive voice are (i) many theses are written in the passive voice, and (ii) some very polite people find the use of "I" immodest.”

I have intentionally written in a rather personal style for two reasons:

- First, the results given in this thesis are tightly connected to my personal experiences. I want to be very clear on what are my experiences and opinions, and what are someone else’s. It would be very ‘nonscientific’ and ‘nonserious’ to write in an impersonal style using the passive voice, trying to make the results look more general than they are.
- Second, I want people in industry, outside the academic world, to read this thesis. Maybe I will not succeed in this since, for a non-academic, there are quite a lot of seemingly irrelevant references in the text. As a help to the reader, I have created reading instructions (page iii) so that different readers could find the specific chapter of interest to them.

I do not consider myself a saint, but I feel as if I have something in common with saint Hildegard of Bingen (1098-1179). The quotation on the second title page (page ii) is from a letter she wrote in 1175 addressed to the monk Guibert of Gembloux. She writes “in unpolished Latin” what she has seen in her visions, i.e. her revelations from God. I write in unpolished English what I have seen in my visions, i.e. my experiences in industry. I also agree with her that “I have not been taught to write in the vision as philosophers write”.


CHAPTER 3
AN ENGINEERING MANAGEMENT MODEL FOR IMPROVEMENT OF ORGANIZATIONAL LEARNING

In this chapter a new theoretical model for engineering management is proposed. The purpose of the proposed model is that it should facilitate improvement of organizational learning within a product development organization. The chapter is principally built on a working paper, co-written with Ingrid Samuelson at Chalmers University (Cronemyr and Samuelsson, 1999). Some of the material was first presented in a short paper at QERGO99 (Cronemyr, 1999).

3.1 INTRODUCTION

In this chapter I am addressing my second research question:

RQ2: How to improve organizational learning within a product development organization?

I propose an engineering management model as a possible solution to RQ2. The purpose of the proposed model is that it should facilitate improvement of organizational learning within a product development organization. Hence the question is transformed into:
RQ2a. *Does the proposed engineering management model constitute a tool for improving organizational learning within a product development organization?*

In the next section three dimensions of engineering management - *domain, concept,* and *knowledge* - are identified. In the following section the relations between three engineering management disciplines - *project management, holistic product development,* and *knowledge management* - expressed in the three dimensions are found. Then, in Section 3.4, the three dimensions and the three disciplines are synthesized into a new theoretical model for engineering management and, in Section 3.5, Senge’s five disciplines of a learning organization (Senge, 1990) are identified in the engineering management model. Finally I conclude whether the purpose of the model is fulfilled.

### 3.2 Dimensions of Engineering Management

Engineering management is a very broad area, covering many different issues. In this chapter I am addressing the issues that relate to management of work within a product developing organization. In that scope I identify and use three dimensions - *domain, concept* and *knowledge* - that can be used to differentiate and relate the three engineering management disciplines described in the following section.

#### 3.2.1 Domain dimension

Since the beginning of the 20th century most engineering activities within large organizations have been divided in some way. The most common division of labour has been, and still is, the decomposition of work into functional units capable of performing specific tasks, i.e. the principle of specialization (Taylor, 1911). That is what we first think of when we talk about engineering domains, i.e. traditional engineering disciplines sometimes defined already at school, e.g. design and manufacturing. A domain can also be the common knowledge of a group of people who all run a specific software, even though they may not be members of the same organizational unit. What defines a domain is a specific language built on specific knowledge. Sometimes, a group of people who share knowledge and language is referred to as a domain, even though it is actually the common knowledge of these people that constitutes the domain.
The problem is that these domains very quickly become more or less closed to the people outside the domain borders since the people within the domain are developing their own language built on domain-specific knowledge - theoretical or experiential. One thing that is evident is that engineers do not want to step into another domain and ask ‘silly’ questions (Allen, 1977). Instead the engineers focus on developing new knowledge and becoming more skilled within their own domain, which is a good thing for the domain, but this behaviour could cause problems for the system as a whole since the domain-specific knowledge serves as a fence around it (see section 3.2.3 ‘Knowledge dimension’).

One of the main objectives of engineering management is to tear down these domain fences. W. Edwards Deming’s approach to quality management - an important influence on engineering management - are summarized in ‘Deming’s 14 points’ (Deming, 1982; Bergman and Klefsjö, 1994). One of the points (no. 9) is ‘Break down barriers between staff areas’. Deming argues that many of today’s quality defects are due to lack of communication between different departments of the company. Breaking down barriers aims at minimizing suboptimization and misunderstandings.

3.2.2 Concept dimension

In engineering management it is often necessary to differentiate between concrete and abstract concepts. As an example, a specialized task is a concrete concept while the purpose of the task is an abstract concept. E.g. the bricklayer who lays bricks on bricks performs a very specialized task. Laying bricks is a concrete concept. Next to him there is another bricklayer who is building a cathedral. He knows that the work he is doing has to be coordinated with others to meet some common goals like fulfilling the specified quality and performance in the specified time. Quality - the ability to satisfy or exceed the needs and expectations of a customer (Bergman and Klefsjö, 1994) - is an abstract concept.

Abstract concepts can be shared by people from different domains as a common view on a set of concrete concepts even though the concrete concepts may only be understood in detail within a certain domain. The purpose of a common abstract concept, e.g. a common abstract task, is that everybody should have a common goal, i.e. to fulfil the goal of the common task.

To transform abstract concepts into concrete concepts, i.e. to assign specific tasks for each person involved in the building of the cathedral, used to be the main objective within engineering management. For some decades now, the objective within engineering
management has become to make everybody aware of how their specific concrete concepts
relate to the common abstract concepts, e.g. holistic view, process view, system view, and goal
sharing (see section 3.3.2 ‘Holistic product development’).

3.2.3 Knowledge dimension

The third dimension that I use in this thesis to relate the engineering management disciplines is
the depth of knowledge, spanning from superficial knowledge to profound knowledge.
Superficial knowledge is ‘quick words without explanation’ which is easy to share or receive.
Profound knowledge\(^5\), which means ‘having an intellectual depth and insight’, is built on
continuous learning and experience, requires more effort and time to gain, and is more difficult
to share or receive. Profound knowledge is more complex than superficial knowledge The
Danish science journalist Tor Nørretranders discusses complexity of knowledge: “A simple
statement may require an enormous effort of thought. Without showing. It is difficult to make
“A statement has depth if it consists of much ‘exformation’, i.e. information that has been
excluded from the message and is no longer a part of the final result.” (My translation from:
Nørretranders, 1993, p.132). For two people to understand one another, Nørretranders
emphasizes the importance of common ‘exformation’, or ‘speaking trees’ (Nørretranders, 1993,
p.154), which could be called domain knowledge.

Assuming that sharing of profound knowledge is an important task, the question that I will
discuss further is, ‘How is knowledge transferred?’.

Transfer of knowledge between people is a social process (Nørretranders, 1993; Verkasalo and
Lappalainen, 1998). What is transferred is actually not knowledge but information (or data) and
the process includes making the information available in such a way that the receiver can see
new patterns in it and relate it to previous knowledge, experience and theories. Hence the
knowledge created is the receiver’s interpretation of the transferred information. One important

\(^5\) In this thesis I choose to use the Webster dictionary definition of the word *profound* which is “having
an intellectual depth and insight”. I do not refer to the four components of Deming’s profound
knowledge (Deming, 1994), i.e. (i) systems thinking, (ii) knowledge about variation, (iii) theory of
knowledge, and (iv) psychology, even though Deming’s profound knowledge also could be
characterized as “having an intellectual depth and insight”.

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The effect of transfer of information is that the receiver may detect new patterns in her/his own knowledge. The new information may not only fill in gaps in the existing knowledge but also render it new meanings.

When we try to express our interpretation of a set of data in the hope that the listener or reader is going to make a similar interpretation, we are expressing explicit knowledge. The listener who remembers the words that we use, i.e. the data, but does not see the same patterns as we do, has some superficial knowledge about your topic but does not fully understand what you understand. You have a deep, profound knowledge of a specific subject, built on continuous learning and experience. Most of that knowledge is actually patterns that you can not express explicitly. That is tacit - or silent - knowledge (Polanyi, 1966; Nonaka and Takeuchi, 1995). Profound knowledge consists of both explicit knowledge and tacit knowledge, which people outside the domain do not posses. A comparison of tacit and explicit knowledge is given in table 11.

Nonaka and Takeuchi describe the process of knowledge transfer as a ‘knowledge spiral’ between tacit and explicit knowledge, see figure 6. It includes the four modes of knowledge creation: socialization, externalization, combination, and internalization. Nonaka and Takeuchi discuss these modes at different organizational levels. In the context that I discuss in this thesis I consider two levels: conversion of knowledge for one person, and conversion of knowledge when transferring knowledge from one person to another. Nonaka and Takeuchi also discuss knowledge conversion at higher organizational levels.

Briefly the four modes in the knowledge spiral can be described by the following process. When a person learns the tacit practices of his/her domain (i.e. department or discipline) by looking, acting and participating in day-to-day work, we are talking about socialization. When that person is going to explain to someone outside the domain what he/she actually knows, he/she has to start by explaining it to himself/herself, i.e. turning tacit knowledge into explicit

<table>
<thead>
<tr>
<th>Tacit Knowledge</th>
<th>Explicit Knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjective</td>
<td>Objective</td>
</tr>
<tr>
<td>Knowledge of experience (body)</td>
<td>Knowledge of rationality (mind)</td>
</tr>
<tr>
<td>Simultaneous knowledge (here and now)</td>
<td>Sequential knowledge (there and then)</td>
</tr>
<tr>
<td>Analog knowledge (practice)</td>
<td>Digital knowledge (theory)</td>
</tr>
</tbody>
</table>

*Table 11 Two types of knowledge (Nonaka and Takeuchi, 1995)*
he/she can ‘tell’ others what he/she knows and they can listen to what he/she says and add the new explicit knowledge to their previous knowledge. That is called combination. If the listeners remember the new knowledge (if they found it uninteresting or did not understand it, they will forget it), then they can start behaving in a new way, making use of the new knowledge. After some time they do not think about what the person from the other domain was talking about, they just know it and behave differently due to the new knowledge. That is internalization. Finally, when other people see the new behaviour, they will be influenced to change their behaviour. Tacit knowledge from one person has been transferred to tacit knowledge of another. Once again, that is socialization. Now we have travelled one lap in the knowledge spiral. Now we can continue by trying to express in explicit knowledge why we do as we do.

In the way we work today in the western world we do not realize the value of tacit knowledge. Managers in the west are facilitating transfer of explicit knowledge as opposed to Japanese management which recognizes the importance of all four modes of knowledge conversion (Nonaka and Takeuchi, 1995). As an example, told to me by one of my managers who frequently visits Japan, Japanese managers often let younger engineers sit in on meetings. They sit along the walls, never speak but take notes feverishly. It is a part of their on-the-job training and when they compare notes they enhance both their explicit and their tacit knowledge.
It is common that people within a domain share both explicit and tacit knowledge. They understand one another’s interpretations of the same data - though not totally. When two domains overlap, the intersection of the two domains is knowledge, which enables a common language, see figure 7. Nonaka calls this redundancy and identifies this as an organization-wide enabling condition that promote knowledge creation. “Since members share overlapping information, they can sense what others are trying to articulate” (Nonaka, 1994, p.28).

Even though some researchers have paid attention to techniques for sharing and developing knowledge in the last decade, many managers and some - other - researchers are still talking about IT as the solution to the lack-of-knowledge-overlapping problem. IT is a tool for managing information, not knowledge. One of the most important tasks for engineering management in the next decade will be management of the knowledge creation and sharing of profound knowledge. It is not a matter of IT. Nonaka has emphasized that only human beings can take the central role in knowledge creation and argues that computers are merely tools, however great their information processing capabilities may be. To ensure that misunderstandings due to superficial knowledge are avoided as far as possible it is important that managers and employees should become more aware of the difference in quality of superficial knowledge (i.e. data) and profound knowledge.

### 3.3 Engineering Management Disciplines

During the years several disciplines of management have evolved within the area of engineering management. The three that I choose to discuss in this chapter - project management, holistic product development, and knowledge management - are all focusing on communication between domains, i.e. in the first dimension mentioned above. What differentiates these three
Disciplines is the content of the communication between the domains expressed in the second and third dimension, i.e. concept and knowledge.  

3.3.1 Project management

The objective of project management, as traditionally applied in industry, is to coordinate the tasks of a project in the most efficient and effective way in order to meet the goals of time, cost and quality (Engwall, 1995). Flowchart techniques, e.g. GANTT and PERT charts (Hillier and Liebermann, 1986), implemented in software such as MS Project, are commonly used tools. Planning of the activities is commonly done with the critical path method where the chain of activities taking the longest time determines the total project time.

The keyword in project management is ASAP, as soon as possible. A common way to shorten the total project time for a product development project, in addition to optimizing the task sequence, is to shorten the specific task times by utilization of common IT tools, models and data, hence shortening the time for input and output to/from the activities.

Only concrete concepts and superficial knowledge are transferred between different engineering domains (see figure 8). In project meetings there is no time to talk about profound or tacit knowledge and the IT tools only relate the concrete concepts in different domains. As a consequence a project needs a skilled and experienced ‘heavy weight’ project manager as the central coordinator (Clark and Wheelwright, 1992). Such people do exist but most of the time

---

6. Another management discipline - not used here - with more focus on control than on communication is the bureaucratic management of authority in a hierarchic organization.

7. What I call engineering management some may want to call project management and argue that holistic product development and knowledge management are parts of modern project management, but I choose to use the traditional definitions that are mostly used in industry.
the work load is just too heavy for a single person. That is why alternative management disciplines have been introduced in industry in the last decade.

### 3.3.2 Holistic product development

The main theme in holistic product development is the word holistic, i.e. to see the whole. It can be seen more or less as a reaction to traditional project management where the holistic view was missing. Holistic product development is actually a combination of many disciplines, e.g. process management (Harrington, 1991; Davenport, 1994; Bergman and Klefsjö (1994), Rentzhog, 1996), systems/concurrent/simultaneous engineering (Wheelwright and Clark, 1992; Clausing, 1994; Ulrich and Eppinger, 1995; Smith and Reinertsen, 1998) and integrated product development (Andreasen and Hein, 1987; Norell, 1992).

Common to all these disciplines is the focus on sharing the goal and a holistic view of the development process (see figure 9). The intention is to create an understanding of how my concrete task and the concrete tasks of people from other domains are connected to one another and to the over-all abstract goals of the common process. This leads to insight of what is really important and what is not in the work I am doing. It prevents suboptimization and it will reduce conflicts due to unclear roles and field of responsibility between domains. In this way holistic product development tries to ensure that the abstract concept of quality is transformed into specific concrete concepts for each engineer and domain.

Holistic product development has been successful in certain parts, see e.g. the above-mentioned references and also the GE Pilot Project Case Study Report (1992). Unfortunately many companies have used process management tools like process mapping and re-engineering merely for speeding up task execution rather than creating a holistic view. Furthermore, there
have been some criticism that the process view in process management and the systems view in systems engineering are rather inhuman. The humans in the system are vital parts of the system since they possess the knowledge of the system.

### 3.3.3 Knowledge management

Verkasalo and Lappalainen (1998) present three “well-known schools of Knowledge management”. A short summary of these is given in table 12. As seen in the previous section ‘Knowledge dimension’, my focal point is within the “Knowledge Creation School”.

Tom Allen identified the need for engineers to deeply understand colleagues at other departments but also the difficulties in achieving such knowledge (Allen, 1977). In the nineties Ikujiro Nonaka has been one of the most influential researchers within the Knowledge Creation School of knowledge management (Nonaka, 1994; Nonaka and Takeuchi, 1995). Nonaka compares the Japanese-style versus Western-style organizational knowledge creation. The main difference is in the knowledge dimension. In Japan management is facilitating the sharing of tacit knowledge as opposed to Western management styles where the focus is on transfer of explicit knowledge.

In organizations performing holistic product development in co-located cross-disciplinary teams with common tools and data, the engineers from different domains still have difficulties in understanding one another. It is a question of language. Davenport and Prusak (1998)

<table>
<thead>
<tr>
<th>Knowledge Management School</th>
<th>Assumptions and Focal Points</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge Creation School</td>
<td>Knowledge exists in two forms: tacit and explicit. Focus on knowledge creation and transfer.</td>
<td>Nonaka and Takeuchi (1995)</td>
</tr>
<tr>
<td>Core Competence School</td>
<td>Core competencies are vital for a company. Business-oriented approach of knowledge creation.</td>
<td>Prahalad and Hamel (1990)</td>
</tr>
<tr>
<td>Knowledge Base School</td>
<td>Effort to make an intelligent machine. Artificial intelligence, expert systems, and knowledge bases.</td>
<td>Ram and Ram (1996)</td>
</tr>
</tbody>
</table>

Table 12 Knowledge management schools (Verkasalo and Lappalainen, 1998)
examine the work by Allen and Nonaka and conclude: “Research shows time and again that a shared language is essential to productive knowledge transfer. Without it, individuals will neither understand nor trust one another” (Davenport and Prusak, 1998, p.98), and “Giving people who work together at the same location opportunities to talk to one another does not by itself solve the problem of transferring knowledge [...] We also need to consider more formal and intentional ways of sharing knowledge within organizations” (Davenport and Prusak, 1998, p.95). In knowledge management the focus is on developing and sharing knowledge to get a common language (see figure 10). With a common language the misunderstandings will hopefully disappear or at least decrease. Misunderstandings can be of two types. The first is that I hear a word or sentence and misunderstand it. I do not have the requisite knowledge to make the right interpretation, as discussed earlier. The other type of misunderstanding is when I do not ask a question about something that I need to know because I do not know that I need it. Both types have severe consequences. The misunderstandings, if not caught in the design process, usually become obvious later when the designed product can not be produced, does not meet the specified performance or just does not fit the customer’s needs - in other words far too late.

Allen and Nonaka present strategic rotation, i.e. to move people around at departments, as a way to build redundancy in an organization but there is still no management tool to quickly improve redundancy. It is also a weakness that there is no obvious connection between knowledge management and the other management disciplines.
When a new management style appears in industry it is often said to be ‘the new management style that will succeed where the old ones failed’. A new buzz word is created. What we really need is a synthesis of the strengths of the different management disciplines, e.g.:

- Project management - Common plans, tools, models and data for *fast execution of tasks*.
- Holistic product development - Goal sharing and a common *holistic view* of the process.
- Knowledge management - Methods to share knowledge to get a *common language*.

By superimposing figures 8, 9 and 10 we get figure 11. Now we can see how the disciplines overlap in the three dimensions and how the communication paths of the three management disciplines mapped in the three dimensions constitute an Engineering Management Model.

The model can be used to see how the three dimensions - *domain, concept and knowledge* - can be used to differentiate and relate the three engineering management disciplines - *project management, holistic product development and knowledge management*.
Successful engineering management, utilizing the strengths of all three management disciplines, depends on an organization’s ability to integrate the management disciplines i.e. use all three communication paths in the model.

How can the model help the organization to develop such ability? In the next section I will explore in what ways the Engineering Management Model can be used as a tool actively integrating the suggested management disciplines to improve organizational learning within a product development organization.

3.5 USING THE ENGINEERING MANAGEMENT MODEL TO IMPROVE ORGANIZATIONAL LEARNING

In this section I first discuss organizational learning and the learning organization, and then go on and identify Senge’s five disciplines of a learning organization (Senge, 1990) in the Engineering Management Model developed in the previous sections.

3.5.1 Organizational Learning and the Learning Organization

Barnett (1994) presents a composite of fifteen definitions (dated 1963 through 1991) of the term ‘organizational learning’ as:

Organizational learning is an experience-based process through which knowledge about action-outcome relationships develops, is encoded in routines, is embedded in organizational memory, and may change collective behavior.

Garvin (1993) proposes a similar definition for a ‘learning organization’:

A learning organization is an organization skilled at creating, acquiring, and transferring knowledge, and at modifying its behavior to reflect new knowledge and insights.

Both definitions stress an action of change in behaviour from new knowledge and insights. Barnett states ‘Learning requires change, but change does not require learning’ (Barnett, 1994). Another discussion is whether or not learning always produce a change in behaviour (see e.g. Philips and Soltis, 1991). I conclude that what we are striving for is an organization that learns - from mistakes or planned actions - and change behaviour accordingly, i.e. ‘double loop
learning’ (Argyris, 1977). A ‘learning organization’ is a vision of an ideal condition of the organization - which we may not ever achieve - where ‘organizational learning’ is the process that we use in trying to get there.

### 3.5.2 Senge’s Five Disciplines

Peter Senge’s book ‘The fifth discipline - The art and practice of the learning organization’ (1990) was a break-through for the concept of a learning organization, even though researchers had known it before from the works of e.g. Argyris (1977), Hedberg (1981) and Deming (1982).

To enhance the organization’s capacity to learn, Senge proposed the learning organization defined by the following five ‘disciplines’ or ‘competent technologies’:

- Shared vision
- Mental models
- Personal mastery
- Team learning
- Systems thinking

All disciplines are of importance and strongly coupled to the others but the most important discipline is systems thinking. Senge emphasizes that “it is important that the five disciplines develop as an ensemble. This is challenging because it is much harder to integrate new tools than simply apply them separately. But the payoffs are immense. This is why systems thinking is the fifth discipline” (Senge, 1990, p.12).

Senge describes the contents of the disciplines as follows:

The essence of building a shared vision is that throughout the organization there exists a feeling of partnership and common purpose. This includes recognizing the existing reality and working with the vision in a process that includes communicating personal vision and listening to others, in an atmosphere that is characterized by freedom of choice

The essence of mental models is to be open and truthful towards what is going on around you and have an awareness of your internal, mental model of the situation. This includes continuously testing assumptions, openly expressing underlying thoughts, views and emotions as truthfully and honestly as possible. And also to be aware of the distinction between data and conclusions drawn from data.
The essence of *personal mastery* is to be present with your whole being, connected and creative. This includes having clarified your personal vision, handling the creative tension between the desired goal and the perceived reality, together with understanding the power of making choices.

The essence of *team learning* is to create a closely knitted group that uses the combined intelligence of the members. This includes actively working towards a situation where assumptions are suspended, one’s own defensiveness addressed and the group members regard each other as colleagues.

The essence of *system thinking* is to view the company as one system with a specific aim, made up of smaller interconnected systems, that should work not to maximize their individual gain but instead work towards maximizing the gain of the total system. System thinking also includes understanding how different action taken influences, over time, in and between subsystems, using what Senge calls system archetypes.

### 3.5.3 Identifying the five disciplines in the Engineering Management Model

As the concept of the learning organization and the five disciplines have attracted much attention and interest, the question remains: *How to improve organizational learning within a product development organization?* In this section I will try to answer the question by exploring Senge’s five disciplines further and identifying them in the proposed Engineering Management Model.

**Shared vision.** Shared vision is easily located in the top of the model. A vision is an abstract concept that people in a team or an organization can share if they can translate it to specific concrete concepts or connect it to their personal visions. An example of unsuccessful building of a shared vision is when a manager calls everybody in the department to an information meeting where the new ‘shared’ vision is presented. What the boss is talking about is how great every thing is going to be for the company but what the listeners are thinking about is “Am I going to keep my job?”; “How does this affect my position?” and “Do I have to change tasks now?”. Successful building of a shared vision connects each person’s concrete concepts and personal visions to the over-all abstract concepts. A holistic view is not only to ‘look down from above’, it is also ‘looking up from many different spots’ and integrating it all to a shared vision.
Mental models. Mental models are located in the lower ‘white tubes’ below the domains in the model. The definition of a domain is a common language and knowledge. This is to a large extent the same as mental models. People within a domain share mental models. Mental models are not only technical domain knowledge but also consist of views on how concrete and abstract concepts are related, e.g. the view on a work method or process. That is why it is located in the lower part of the model. If we truly want to share mental models in the organization we need more knowledge overlapping, or what Nonaka calls redundancy.

Personal mastery. A person can - of course - be a member of several domains but not of every domain. According to Porras and Robertson (1992), “change in the individual organizational member's behavior is the core of organizational change and, therefore, any successful change will persist over the long term only if, in response to changes in organizational characteristics, members alter their on-the-job behavior in appropriate ways”. Hence personal mastery is a person’s ability to view and question his/her own domain knowledge and his/her ability to share tasks, goals and knowledge with other domains. In the model personal mastery is located in one domain and the use of the three arrows that connect it to other domains.

Team learning. Argyris and Schön (1996) point towards the interdependency between individual and organizational learning. “The learning of individuals who interact with one another is essential to organizational learning, which feeds back to influence learning at the individual level.” Just as personal mastery is a person’s ability to use all three paths in the model, team learning is a team’s ability to use all three paths. A learning team continuously needs to pay attention to coordination and fast execution of tasks, sharing and developing the goal, as well as sharing knowledge to develop a common language. As suboptimizations and misunderstandings become evident the roots of the problems should be looked for in all three ‘directions’. Hence team learning is the three arrows in the model.

Systems thinking. Systems thinking is, as Senge puts it, an ensemble of all five disciplines. Since this means the ability to combine all other disciplines, systems thinking is not located somewhere inside the model. It is the model. Senge uses two words ‘holism’ and ‘interconnectedness’ which very well describe the entirety of the model. Systems thinking is to balance the efforts of the other disciplines. E.g. too much emphasis on building a shared vision may lead to excessively focused domains which will lead to less shared mental models. On the
other hand too much focus on personal mastery may lead to people losing their interest in team learning. Systems thinking is also to see the delays in the system and to focus parts of the organization on different actions that will lead to learning and improved learning skills.

Now we can draw the five disciplines in the model, as can be seen in figure 12. As all five disciplines of a learning organization have been identified in the Engineering Management Model it is evident how the model can be used to facilitate improvement of organizational learning within a product development organization. To start this work the model indicates the importance of sharing and communicating abstract concepts, concrete concepts, tacit and explicit knowledge, in a conscious and balanced way.

Except for the graphical representation of how the five disciplines are related - which is believed to be helpful for some people, particularly engineers - the model shows how continuously applying project management, holistic product development and knowledge management and simultaneously developing skills to work with and combine the three may be a help for improving organizational learning within a product development organization.
3.6 DISCUSSION AND CONCLUSION

3.6.1 Discussion

As expressed in the research question I would like to see a ‘tool’ for improving organizational learning within a product development organization. In the previous section I concluded that applying and combining the three management disciplines in the Engineering Management Model may be a ‘help’ for improving organizational learning within a product development organization. Are ‘tool’ and ‘help’ the same thing?

The model that I present is a tool in the sense that it can be used as a common abstract concept of how to improve organizational learning within engineering management. By using the model people from different domains and different levels in the organization can translate the abstract concept of organizational learning within engineering management to their own concrete concepts of organizational learning. This ensures a process where the personal concepts are in accordance with the organization’s i.e. others’ personal concrete concepts and the organization’s overall goal. By sharing the knowledge behind these concrete concepts and hence developing redundancy in the organization we can hopefully get a shared mental model of organizational learning within product development. I.e. the abstract ‘tool’ can serve as a concrete ‘help’ when improving organizational learning within a product development organization.

As it is an abstract model, it can be used for different purposes at different levels in the organization. At a high management level it can be used to coordinate activities and resources for building a learning organization. At a lower level it can be used to focus on domain-specific or team-specific issues to develop learning. Somewhere in between it could be used to connect company-wide visions with every-day work at the lower levels. This is similar to what Nonaka calls Middle-up-down management in a Hypertext organization (Nonaka, 1994, 1995).

3.6.2 Conclusion

Returning to the research question RQ2a ‘Does the proposed engineering management model constitute a tool for improving organizational learning within a product development organization?’, I conclude that it does. I base the conclusion on a) ‘organizational learning’ aims at establishing a ‘learning organization’, b) a ‘learning organization’ can be described by Senge’s five disciplines, c) the five disciplines can be identified in the Engineering Management
Model, d) the model is defined by three - individually - well-known and successful management disciplines of engineering management and hence e) by combining and developing these management disciplines together we can facilitate improvement of organizational learning within a product development organization.

The graphical representation of Senge’s five disciplines in the Engineering Management Model can also be used as a common abstract concept of how the five disciplines are related to one another and to the three engineering management disciplines.

The model presented is a theoretical model. To apply the model practically in a product development organization we need practical methods for applying the three paths in the model. In the following three chapters I will present one method for each path in the model. The purpose of these methods is that they should be possible solutions to my first research question RQ1 ‘How can understanding between engineers from different backgrounds in a product development organization be improved?’. Applying them together could be one practical solution to RQ2 ‘How to improve organizational learning within a product development organization?’
CHAPTER 4

PHANTOM TURBINE DEVELOPMENT

In this chapter I present the concept of Phantom Turbine Development, as it was organized at ABB STAL in 1998 when I participated in the work in the process team for the complete development process. In Phantom Turbine Development, development of technology and process for product development are combined with common shared goals built on future customer needs.

4.1 INTRODUCTION

In this section the concept of Phantom Turbine development at ABB STAL is presented. The Phantom Turbine - a turbine that neither exists, nor is intended to ever exist - represents the common goal which unifies the parts of the R&D organization involved in technology, and process development producing technologies and processes to be used in future gas turbine development projects. The main objective and advantage of Phantom Turbine development is goal sharing and customer focus.

8. Since 1998 ABB STAL has become a part of the new global power generation company ABB ALSTOM POWER which has lead to major re-organizations to coordinate product development within the new company. The organization of Phantom Turbine development as presented in this thesis, agrees with the organization at ABB STAL in 1998. The organization now in 2000 is under development (see <http://www.abb-alstom-power.com>, April 2000).
An example of a gas turbine developed at ABB STAL, the 43 MW industrial gas turbine GTX100, unveiled on the 26th of May 1997, is shown in figure 13.

**Figure 13  The gas turbine GTX100*, developed at ABB STAL.**

*For more information, see: <http://www.abb.se/stal/product/indexpro.html>, April 2000.

4.1.1  **Goal sharing within Product Development**

Goal sharing is an important item in the Engineering Management Model presented in the previous chapter but how can it be achieved in a product development organization where engineers are engaged in such different activities as product, technology, and process development?

Clausing (1994) emphasizes the difficulty of integrating technology and product development. Even though there are advantages with separate technology and product development organizations Clausing argues that “*We must take care that our organization is not characterized by cloistered groups of technical specialists looking inward within their own speciality*” (Clausing, 1994, p.320) and “*Technology transfer can be very difficult. In the past, there has been an unfortunate tendency toward rivalry between the product engineering division and the technology organization.*” (Clausing, 1994, p.335). As too often is the case, solving a technical problem or a strategic problem transforms into solving the problem of clash of cultures within the organization. Wheelwright and Clark emphasize ‘future customers’ requirements and needs’ as a mechanism for eliminating rivalry and getting everybody on the same track. “*The most powerful mechanism to achieve integration across functions and yet*
obtain excellent solutions to functional problems, is customer focus. It requires the capability to translate the customer’s needs into terms that everyone can understand.” (Wheelwright and Clark, 1992, p.162).

4.1.2 Purpose of the chapter

The purpose of this chapter is to present the concept of Phantom Turbine, developed at ABB STAL. Even though some comparisons are made to product, technology, and process development as presented in the literature, the purpose is not to give a thorough review of the product development literature. It is suggested that Phantom Turbine Development could be one practical tool for realizing the ‘holistic view’ in the Engineering Management Model with emphasis on goal sharing.

4.2 PHANTOM TURBINE DEVELOPMENT AT ABB STAL

First, the context of the core processes at ABB STAL is presented. The decomposition of one of these processes, ‘Develop Products’, is presented. Second, the processes for technology development and process development are described. Finally, the organization of Phantom Turbine development is presented. During the presentations comparisons to related concepts in the literature are made.

4.2.1 The story of the Phantom Turbine

The Phantom Turbine concept started to evolve at ABB STAL in the middle of the 1990s. The influences came from the different projects, mainly in the U.S.A., where advanced technology was developed in order to meet strategic requirements for future products. To be able to develop future products some people at the R&D department saw a need for developing its core competencies and technologies in a strategic way.

When I entered the process team for the complete development process in 1998 the Phantom Turbine concept and the Phantom Turbine project were already established. When I asked - in the preparation of this chapter - who had invented the concept several people took the credit. The manager of the R&D department presented the Phantom Turbine concept for the first time in 1996 at a meeting for cooperation on technology development for gas turbines at an ABB
office in Switzerland. Two other engineers claim to have invented it in the business lounge at Munich airport at approximately the same time. This shows that the ideas had been around within the R&D department for a while.

Initially, the purposes of the Phantom Turbine were:

1. To allocate money and resources for long-term competence development ("Top management do not understand the need if it is not related to a 'real' product").
2. To have technologies (initially) and processes (added in 1997) ready when they are needed (pre-developed modules).
3. To make the product development process more efficient by making the right competencies available at the right time.
4. To make ‘researchers’ and technical specialists ("a resource hard to control") more focused on a well-defined goal.

I was one of those who took the initiative to include development of the product development process in Phantom Turbine development in 1997. The main goal within Phantom Turbine development is to make it possible to develop the Phantom Turbine in the future to be able to meet future customer needs, even though the Phantom Turbine never will exist. Other gas turbine projects will benefit from the development carried out within the Phantom Turbine project.

### 4.2.2 Core Processes

ABB STAL has been involved in process orientation work for over a decade. In 1997 top management at ABB STAL declared that the complete company should be process oriented for customer focus. This resulted in extensive process development work throughout the organization and emphasis was put on the core processes of the company, see figure 14. The core processes were ‘Develop Products’, ‘Sell Products’, and ‘Deliver Products’. One typical aspect of a gas turbine is that it is not manufactured until it has been sold. The delivery of a gas turbine (or a complete power plant including a gas turbine) includes manufacturing, erection (i.e. construction on site), and commissioning (i.e. starting up the plant). As can be seen in figure 14, the core processes are running concurrently, with several projects using the same process, and with completely different cycle times. Furthermore, all three processes are customer-related. Even though the processes are completely different from each other, the
customers are in focus. Of course there are interactions between the three processes but these have been omitted in figure 14 for simplicity. For instance feedback from production is given to the development process, and of course production people participate in product development. In addition to the core processes there are management processes and support processes (not included in the figure) which cut through the core processes. The processes ‘Sell Products’ and ‘Deliver Products’ are not described further in this thesis.

**Comparisons to Core Processes in the literature**

In process management - a branch of quality management - the significance of process thinking is emphasized (Bergman and Klefsjö, 1994). In figure 15 the concept of a business process according to Bergman and Klefsjö is presented. A business process cuts horizontally through the organization with customer focus as its main objective, “from customer needs to customer...
Figure 15 A business process, “From customer needs to customer satisfaction”, according to Bergman and Klefsjö (1994).

Figure 16 Core process selection according to Rentzhog (1996).

Figure 17 An example of three generic core processes. (From Nilsson (1999), originally from Loinder (1996) in Swedish).
satisfaction”. The most important business processes of a company are often referred to as core processes (Rentzhog, 1996). A core process fulfills one or more sub-missions of the overall mission of the company (see figure 16). An example of three generic core processes for a product development organization is given by Nilsson (1999) in figure 17: ‘Development of strategic plans’, ‘Satisfy the present need of the customer’, and ‘Satisfy the future need of the customer’.

### 4.2.3 The Product Development Process

As seen in figure 14, the development process at ABB STAL is called ‘Develop Products’. It includes the sub-processes ‘Develop Product Portfolio’, ‘Technology and Process Development’, and ‘Execute Product Development Projects’, see figure 18.

The process for execution of product development as described in the product development literature (see comparisons to literature below) is included in the sub-process ‘Execute Product Development Projects’, see figure 19. Input is a product development specification, i.e. a turbine specification, from the process ‘Develop Product Portfolio’. Output is a documented
developed new/improved product. The process is not very detailed, the focus is on phases that are defined by the decision points: ‘Specify manufacturing system’, ‘Specify materials acquisition’, and ‘Specify prototype manufacturing and test’. The facts that some components take a very long time to develop, with high involvement from manufacturing, and that some materials have to be acquired very far in advance, complicate the process. The development of some components may actually be at Level ‘A’ at the same time as others may be at Level ‘C’. In order to shorten the development time there is a the need for pre-developed modules and core competencies when the project starts.

For development of components (or sub systems), there are specific sub-process maps. An example can be viewed in figure 39 on page 94 (the gas turbine blade development process) which clearly shows the iterative nature of product development.

In addition to delivering new or improved developed products the process ‘Execute Product Development Projects’ also gives process performance feedback to ‘Technology and Process Development’, see figure 18.
Phantom Turbine development starts in the process ‘Develop Product Portfolio’ with the development of product plans and technology strategy which form the Phantom Turbine specifications which specify which products that the company should be able to develop in two, five, and ten years from now. The Phantom Turbine specifications are input to ‘Technology and Process Development’ which should develop core competencies, technologies and processes to be used in ‘Execute Product Development Projects’. As mentioned by Clausing as well as Wheelwright and Clark (referred to in section 4.2.4 ‘Technology Development’), this will lead to shorter product development projects and more robust products. That is actually indicated in figure 18 by letting the arrow from ‘Technology and Process Development’ enter in the middle of ‘Execute Product Development Projects’, indicating a possible halving of the product development time.

Even though the Phantom Turbine specifications are developed within ‘Develop Product Portfolio’ the main Phantom Turbine development work is performed within ‘Technology and Process Development’. In the following sections I will describe the two processes ‘Technology development’ and ‘Process development’ and finally how these two are coordinated and combined within the Phantom Turbine development organization.

**Comparisons to Product Development Processes in the literature**

Different views on the product development process are presented within the so-called ‘product development literature’ which consists of literature of several disciplines, e.g. engineering design, systems engineering, concurrent engineering, simultaneous engineering, and integrated product development, together simply called ‘product development’, see section 3.3.2.

Within the product development literature the product development process is commonly described as a sequential flow of activities divided into project phases, e.g. ‘concept design’, ‘preliminary design’, ‘detailed design’, and ‘manufacturing and testing’, see e.g. Olsson (1976), Andreasen and Hein (1991, see figure 20) or Ulrich and Eppinger (1995, see figure 21). This sequential view resembles a stage-gate model used in project management (Cooper, 1993; Nilsson, 1999). The objective of dividing the process into phases separated by mile stones (go/kill gates) is to control the development of the project in terms of cost, time and achieved results.
Figure 20  The process for Integrated Product Development according to Andreassen and Hein (1991). (Originally from Olsson, 1976)

Figure 21  The product development process according to Ulrich and Eppinger (1995).

The development funnel...
...in theory:...
...and in practice:...

Figure 22  The product development process viewed as a Development Funnel, in theory and in practice, according to Wheelwright and Clark (1992).
The major disadvantage of these sequential process views is that they do not indicate the iterative nature of the development process. Ulrich and Eppinger (1995) - even though iterations are not shown in figure 21 - deal with approaches for shortening the time for a development project taking iterations into account (see further section 5.1.1 ‘Iterative development process’).

Wheelwright and Clark (1992, see figure 22) view the development process as a Development Funnel which - in theory - looks very sequential and does not indicate any iterations, but - as they found in numerous development projects studied in industry - the development process in reality never looked like a sequential process. Instead the ‘in-practice funnels’ looked very complicated and indicated that iterations took place.

Another view of the development process that sometimes also has been accused of being too sequential (Backlund, 2000) is the systems development process (figure 23). If one does not consider the feedback arrows in figure 23, the process is completely sequential, but the complete picture indicates possible iteration loops at several levels of integration. This picture captures very well the iterative nature of the development process for highly integrated systems (e.g. gas turbines, aircraft or cars). The reason for not considering the feedback loops is most often that iteration is not considered a good thing. The view that re-doing things is bad is still common within project management.

Integration at different levels - function, component, or people - is a topic in many views on the product development process, not only in the systems development process (Danilovic, 1999). Andreassen and Hein (1991, see figure 20) propose Integrated Product Development where the disciplines of Marketing, Design, and Manufacturing are working concurrently and integrated with a holistic view on the process. The process in the figure starts with “the need” of the customers and flows, concurrently (but without any indicated iteration) downstream to selling of products to customers. Now, at the end of the 1990s and the beginning of the new century, ‘customer focus’ has become an even more important part of the development process (Nilsson, 1999).

In the system development process customer focus has always been present. Even though there has been more focus on ‘verification’, i.e. “Does the system meet the specifications?”, the process also includes ‘validation’ which means “Does the specified system satisfy the customer’s needs?”. 

65
In 1998 the technology development process at ABB STAL had been refined to the process shown in figure 24. The input to the process ‘Technology Development’ is Phantom Turbine specifications. In each one of these specifications (one for each scenario) performance, cost, emissions and so on for a future fictitious gas turbine are stated. The first step in the process is to compare these values to the performance of a gas turbine that the organization is capable of developing today, by use of ‘technology road maps’ (see e.g. Wheelwright and Clark, 1992). The gap and how that gap is planned to decrease over the following years constitute the performance road map.

The next step is to identify what components and sub-systems that have to be developed in order to achieve the performance of the Phantom Turbine. That constitutes the Phantom Turbine road map.

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**Figure 23** The iterative nature of the system development process. Adapted from MIL-STD-498 (1994).

Verivation: “Did we build the system right?”; Validation: “Did we build the right system?” (Backlund, 2000)

### 4.2.4 Technology Development

In 1998 the technology development process at ABB STAL had been refined to the process shown in figure 24. The input to the process ‘Technology Development’ is Phantom Turbine specifications. In each one of these specifications (one for each scenario) performance, cost, emissions and so on for a future fictitious gas turbine are stated. The first step in the process is to compare these values to the performance of a gas turbine that the organization is capable of developing today, by use of ‘technology road maps’ (see e.g. Wheelwright and Clark, 1992). The gap and how that gap is planned to decrease over the following years constitute the performance road map.

The next step is to identify what components and sub-systems that have to be developed in order to achieve the performance of the Phantom Turbine. That constitutes the Phantom Turbine road map.
Figure 24 Technology development (a sub-process of the process ‘Develop Products’) at ABB STAL. Actual road maps are confidential.
Finally, in order to be able to develop the new components with the ‘Phantom performance’, key technologies and core competencies that must be developed are identified. This results in technology development specifications which are executed in technology development projects, often by ‘researchers’ and technical specialists.

These projects develop technologies and core competencies but also give requirements on the development processes that have to be improved in order to be able to develop the Phantom Turbine. These requirements are an input to process development.

The technology development projects often span over a long period of time in the process ‘Technology Development’ but the road maps are updated once every year in the process ‘Develop Product Portfolio’. In this way the projects’ results are followed-up and measured against the expected technology improvements.

**Comparisons to Technology Development in the literature**

Wheelwright and Clark establish that “Separating invention from application is one of the few development guidelines upon which everyone (practitioners and academics) seem to agree” (Wheelwright and Clark, 1992, p.38). Clausing argues “A better approach [than to develop everything within a product program] is to develop new technologies outside of any specific product program. When the new technology is sufficiently mature, it is fished out of the technology stream and brought into a program to develop a specific product” (Clausing, 1994, p.317). Clausing’s ‘technology stream’ is presented in figure 25.

According to Clausing, the advantages of a technology stream are:

- To enable time for creativity (without holding a product program hostage)
- To provide a creative environment
- To develop flexible (robust) technologies that can be used in several products.

Wheelwright and Clark describe ‘advanced development’ as an activity separated from ‘commercial development’, see figure 26. However, even though separating technology development from product development projects will lead to shorter product development projects and more robust products, there is still a need for a ‘product and technology integration strategy’ (Clausing, 1994, p.348). “Integrating technology strategy with specific product or
Figure 25 Technology development in the ‘Technology stream’ according to Clausing (1994).

Figure 26 Technology development (or ‘advanced development’) as an activity separated from product and process development, according to Wheelwright and Clark (1992).
process development projects requires an ‘aggregate plan’. Advanced development projects need to be phased to connect in time with the planned development of products and processes.” (Wheelwright and Clark, 1992, p.38).

4.2.5 Process Development

I was one of those who took the initiative to include development of the product development process in Phantom Turbine development in 1997. The main goal for process development is the same as for technology development, i.e. to make it possible to develop the Phantom Turbine in the future. The task within ‘Process Development’ is to develop the product development process and its component-specific sub-processes in order to attain that goal, but also to make improvements to the existing processes.

Inputs to the process (see figure 27) are of three types.

1. Process feedback from product development projects in the ‘Execute Product Development Projects’ process. As problems or improvement suggestions occur in a project, it is fed back to the process owner who notifies the Process Development Team, of which he/she may be a member.

2. Process requirements from Phantom Turbine development within the ‘Technology Development’ process. These requirements state the necessary improvements in the development processes to be able to develop the Phantom Turbine. This also includes interfaces between the development process and other processes. Process requirements are managed within the Phantom Management Team (described in the next section).

3. Company strategy from the ‘Develop Product Portfolio’ process. This includes company goals and long-term strategies, like for instance process orientation principles and management philosophies.

The first activity of the process is ‘Strategic Management of Process Development’. It has the purpose of sending the first two inputs (as mentioned above) to the next activity, i.e. if they are in compliance with the third input above.

The activity ‘Management and Control of Process Improvement Projects’ is the hub of the ‘Process Development’ process. In a Process Development Team, consisting of process owners and managers, process development projects are selected, executed, and terminated. Output is
Figure 27  Process development (a sub-process of the ‘Develop Products’ process) at ABB STAL. I have added and modified the PDSA cycle to indicate the process improvement cycle.
selected processes with improvement focus to the ‘Execute Process Improvement Projects’ sub-process and new or improved processes to the ‘Execute Product Development Projects’ process.

The ‘Execute Process Improvement Projects’ sub-process is where the actual process development takes place. It starts with the formation of a project team who develop a project specification, including goals, schedule, roles, and limitations (i.e. a completely normal project specification). The next step is process analysis and re-design. First the current ‘as-is’ process is mapped (an example of a development process for a gas turbine blade is given in figure 39 on page 94). The root of the current problem is searched for and a list of possible solutions is developed. To rank different - maybe conflicting - process improvements, the process improvement simulation method presented in chapter 5 ‘Process Improvement Simulations’ can be used. The result of the re-design is a ‘to-be’ process map and an improvement action plan.

The carrying out of the suggested improvements could be a part of the project but if it is a major change involving many processes and departments, a new project is formed consisting of the right mix of people and resources.

In figure 27 I have added a modified PDSA cycle (see comparisons to literature below) to indicate the process improvement cycle. Study-Act is performed within ‘Management and Control of Process Improvement Projects’ and Plan-Do is performed within ‘Execute Process Improvement Projects’. The similarities to Bergman and Klefsjö’s improvement cycle in figure 29 on page 74 are evident.

**Comparisons to Process Development in the literature**

The more effort that has been spent on making an ‘official’ development process, the less interest to change it is expected among the people who developed it. With ‘to change’ we usually mean ‘to improve’ but to the people who have just delivered ‘the new perfect development process’ there is no need for improvement. “It is already perfect and, by the way, do you mean that we should re-do the whole project?” We are not used to continuously improving our working methods.

These reactions are well known to researchers within the scientific field of ‘continuous improvements’, a subject within quality management (see e.g. Shewhart, 1931; Deming, 1982; Bergman and Klefsjö, 1994; Elg, 1999).
A well known method for continuous improvement is the ‘PDSA improvement cycle’, also known as the ‘Deming cycle’ or the ‘Shewhart cycle’, see figure 28, (Deming, 1986; Bergman and Klefsjö, 1994).

The main character of the PDSA cycle is that it is cyclical. There is no beginning and no end, just continuity. By travelling a lap in the cycle we learn from our experience and adapt (A) our methods and behaviour accordingly. For instance, no improvement will be achieved by “hip shot” solutions that come from just doing (D) without studying (S) the results. Neither too much planning (P) nor too much measurement and control (S) will result in sustained improvements if we do not go the full circle.

Process development is an application of continuous improvement to a process. To execute a process development (or process improvement) project, Bergman and Klefsjö (1994) present the generic process development process in figure 29. It could be used to develop any process and in particular the development process.

In the product development literature there is not much written about process development of the product development process. One of the exceptions is Wheelwright and Clark (1992) who present five areas of focus for capturing learning how to change the development process, see table 13. Nor do they actually present any process for improving. What they present is more a

![Figure 28 Process development in the quality movement, the so-called 'PDSA improvement cycle', 'Deming cycle', or 'Shewhart cycle' (Deming, 1986; Bergman and Klefsjö, 1994).]
Changing the specific, detailed sequence of activities or rules that developers follow.

Teaching engineers and developers new skills in using specific tools and methods.

Changing the broad sequence of activities and phases that structure development.

Changing the formal organization, the locus of responsibility, and the geographical location of development activities.

Adding to the set of ideas and values used to guide decisions in development.

**Table 13** Five areas of focus for capturing learning how to change the development process *(Wheelwright and Clark, 1992).*
list of solutions than how to find problems and how to execute improvements. However, the five areas of focus that they present cover important aspects of product development and form a good structure for analyzing and improving the development process.

4.2.6 The Organization of Phantom Turbine Development

The organization of Phantom Turbine development at ABB STAL is given in figure 30. It is basically a matrix organization with project management on top and functional management on the side. It looks like a ‘heavyweight’ project organization (Wheelwright and Clark, 1992) but actually it is not. The Phantom Management Team consists of most of the functional managers and the process owners within the R&D organization.

The manager of the R&D organization is the top executive of the Phantom Turbine development organization and is responsible for distribution of resources, as well as starting and terminating Phantom Turbine development projects.

The Phantom Turbine manager is a project manager who is responsible for the results of his specific Phantom Turbine development project and sub-projects. He/she has an ‘advisory board’ called the ‘Phantom Management Team’ including functional managers and the process owners. There are also sub-project managers called ‘Component Managers’. Each one is responsible for technology development and process development for that specific component. There are also ‘systems integrators’ with the task of coordinating development of sub-systems.

As we have seen, the teams performing technology development and those performing process development are working with different but tightly connected tasks and share a common goal of meeting the Phantom Turbine specification.

The engineers participating in these teams are often members of several teams. For instance one and the same engineer could be a member of the development teams for the ‘Blade development process’ and ‘Combustion chamber acoustics technology’, and at the same time work in a product development team as a blade dynamics engineer. That is what I did in 1997.
Figure 30 The organization of Phantom Turbine Development at ABB STAL. The actual organization consists of more components, teams, and team members. Notice that an engineer can be a member of several teams, e.g. both a technology development team and a process development team, or a product development team (not included in Phantom Turbine development).
4.3 DISCUSSION AND CONCLUSION

Recalling the purposes of the Phantom Turbine from section 4.2.1:

1. Resources for long-term development.
2. Pre-developed modules (technology and processes).
3. Competencies for product development.
4. More focused personnel within R&D.

The conclusions are:

1. Phantom Turbines with ‘real’ names have shown top management that long-term development actually means working with ‘real’ products, even though they may not yet exist.
2. Pre-developed modules is a long-term strategy within ABB STAL, not only within product development. The Phantom Turbine concept fits very well into that strategy.
3. Development of competencies within R&D has also been facilitated by the focus on the Phantom Turbine.
4. Finally but most of all, using the Phantom Turbine organization instead of ‘traditional’ separate technology, process, and product development organizations has proved to be very successful in the mission of getting a shared vision and minimizing sub-optimization due to functional departments with too ‘narrow’ a focus.

The concept of the Phantom Turbine is built on a process view with the focus on future customer requirements and needs. This view must be built on the core processes of the company to get a holistic view of the development process. Furthermore, it is important to understand the importance of, and to permit, iterations within product development.

In this chapter I have presented the concept of the Phantom Turbine, developed at ABB STAL. I do not claim that it is better or worse than any other way of conducting product, technology, and process development. I claim that Phantom Turbine Development can be a practical tool for realizing the ‘holistic view’ in the Engineering Management Model with emphasis on goal sharing. As I was actively involved in Phantom Turbine development at ABB STAL, my opinion is that it is a successful concept.

In the next chapter we move one step downwards in the Engineering Management Model, focusing on speeding up iterations.
CHAPTER 5

PROCESS IMPROVEMENT SIMULATIONS

In this chapter a new method for process improvement simulations is presented. I developed the method as an assignment in an ENDREA course on DSM held by Professor Steven Eppinger and developed it further in an application at ABB STAL during 1997 and 1998. The chapter is mainly built on material from a forthcoming paper, co-written with Anna Öhrwall Rönnbäck at Linköping University, and Steven Eppinger at MIT (Cronemyr, Öhrwall Rönnbäck, and Eppinger, 2000). Some of the material was first presented in a short paper at ICED99 (Cronemyr, Öhrwall Rönnbäck, and Eppinger, 1999). The method has also been used and briefly presented by other researchers, see Öhrwall Rönnbäck (1999) and Backlund (2000).

5.1 INTRODUCTION

In this chapter a method for simulating improvements of the development process is presented. The method can be used by managers and teams to prioritize the most valuable process improvements, among several suggested ones, before they actually take place. The method is used to calculate the execution time for a development process, i.e. shorter development time is considered an improvement.

The method is based on the design structure matrix (DSM) developed by Steward (1981), and an extension of DSM called the work transformation model (WTM) developed by Smith and Eppinger (1997). Two new concepts, total process time (TPT) and simulated to-be as-is ratio (STAR) are introduced.
An applications to the gas turbine blade development process at ABB STAL is presented. It illustrates the estimated gain of a process improvement and evaluates the actual implementation.

### 5.1.1 Iterative development process

The development process is often described as a sequence of project phases from conceptual design to production ramp up (see e.g. Andreasen and Hein (1987), Wheelwright and Clark (1992), or Ulrich and Eppinger (1995)). While there have been quite extensive efforts to shift from sequential to parallel and/or concurrent tasks, the problem of iteration between coupled tasks is seldom addressed. Iteration within and between project phases is common in high-tech product development. Iterative development processes are discussed by Eppinger, Whitney, Smith and Gebala (1994), Smith and Eppinger (1997), and MacCormack (1998).

Iteration is a somewhat negative word since it implies re-doing work. Hence the comment “We have to get rid of iterations by doing it right the first time” is - or at least used to be - quite common in process re-design and development. In development of high-tech products, where specialists from several domains have to be involved at the same time, iteration is not a negative word. Some iterations are of great value and even necessary. The problem is that iterations often take a long time to converge, and that the convergence criteria may change (or there may not be convergence criteria at all). To shorten the development time for a development project with iterations, Ulrich and Eppinger (1995) suggest two approaches:

(i) **De-coupled tasks to avoid iterations.** If there is a well-understood interface between two interacting components of the product, it may be possible to de-couple development tasks to avoid iterations. This could be achieved by specifying the interface in advance.

(ii) **Perform faster iterations.** Many of the concurrent engineering tools available today may be used to perform coupled tasks more quickly, *i.e.* to perform more iterations quickly.

In this chapter a method for simulating the impact on the development time from suggested process improvements such as avoiding or speeding up iterations is presented. Fast iterations are required for fast developers, *i.e.* companies which are flexible and capable of rapidly adapting to new market, customer or technology conditions. Being a fast developer is the key to successful product development in many industries (Wheelwright and Clark, 1992, Smith and Reinertsen, 1998).
5.2 CONCEPTS AND THEORY OF PROCESS IMPROVEMENT SIMULATIONS

While much literature discusses the product development process on a highly aggregated level, consisting mainly of product development phases, the process maps that are used in this method are at a more detailed activity level.

5.2.1 Flow charts

Flowchart techniques, e.g. GANTT and PERT charts (Hillier and Liebermann, 1986), implemented in software such as MS Project are commonly used tools. Planning of the activities is commonly done with the critical path method where the chain of activities taking the longest time determines the total project time. A problem, well-known to PERT/CPM users, is that coupled-task iterations cannot be modelled. Instead, the time for iteration loops is estimated. In a GANTT/PERT flow chart the iterations are therefore kept inside black boxes. Such flow charts are not very useful for mapping iterative processes since the iterations are invisible, and consequently uncontrolled. Figure 31 illustrates sequential, parallel, and coupled activities. In figure 32 an example of an iterative process is given.

5.2.2 Design Structure Matrix; DSM

The design structure matrix, as developed by Steward (1981), and extended by Eppinger et.al. (1994) is a technique based on representing the relation between any two activities as a binary (to, from) representation in the matrix cell. Each activity is represented by a row of output relations and a column of input relations. By partitioning the matrix, i.e. re-arranging the rows

![Figure 31 Possible sequences for related activities (Adapted from Eppinger et.al., 1992).](image-url)
and columns in such a way that the activity relations are transferred to the lower triangle of the matrix, it is possible to find sequential, parallel and coupled activities (or activity blocks) in the matrix.  

To transform a flowchart of an iterative process into a DSM one starts to re-arrange the activities and arrows as indicated in figure 33. Then, when the activities are on the diagonal, input arrows horizontal, and output arrows vertical, it is easy to draw the DSM as can be seen in figure 34.

The marks in the matrix indicate what activity output is needed as input to other activities. This is the activity-based DSM (Eppinger et al., 1994). Other uses of DSM include parameter-based, function-based (Pimmler and Eppinger, 1994), people-based, or team-based (McCord and Eppinger, 1993) DSM analysis.

The marks can be exchanged for different icons to show different types of dependencies, e.g. input data needed to start an activity, input data needed to check an activity or input data needed to finish an activity. Different icons or numbers could also show different strength of dependencies, e.g. weak dependency, medium dependency or strong dependency.

---

9. In this application of DSM, no partitioning is necessary. For more information on partitioning algorithms, see the DSM web site: <http://web.mit.edu/dsm>, April 2000.
The work transformation model (WTM) (Smith and Eppinger, 1997) is an extension of DSM. In a work transformation model we use numbers instead of binary marks to show the strength of dependency expressed as rework fractions, with 0.0 meaning no rework and 1.0 meaning 100% rework when new information is transferred from other activities.

In the first iteration loop the activities are carried out without proper input data or rather with **guessed** input data. In the second and following iteration loops the output data from the previous step are used as input data. This is called work transformation. If the process is convergent, the rework decreases as the iteration progresses. When the convergence criteria are satisfied, the iteration stops.

In a WTM the DSM is split into two matrices, the work transformations matrix $A$ and the task time matrix $W$. In figure 35 the task times and re-work fractions from figure 33 have been transformed into $A$ and $W$ matrices.

---

**Figure 33**  Rules for re-arranging the process map. Put activities on the diagonal, make input arrows horizontal, and output arrows vertical.

**5.2.3 Work Transformation Model; WTM**

The work transformation model (WTM) (Smith and Eppinger, 1997) is an extension of DSM. In a work transformation model we use numbers instead of binary marks to show the strength of dependency expressed as rework fractions, with 0.0 meaning no rework and 1.0 meaning 100% rework when new information is transferred from other activities.

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In a WTM the DSM is split into two matrices, the work transformations matrix $A$ and the task time matrix $W$. In figure 35 the task times and re-work fractions from figure 33 have been transformed into $A$ and $W$ matrices.
In the transformation matrix $A$ the off-diagonal elements represent the amount of rework that is generated for a certain activity when another activity is complete. For example, fully re-doing activity 2 will lead to 30% rework of activity 4.

The numbers in the diagonal matrix $W$ represent the amount of time it takes to completely do the activities the first time.

5.2.4 Assumptions

WTM assumes that all activities are carried out in parallel at the same time (Smith and Eppinger, 1997). The assumption of fully parallel activities is acceptable for highly coupled, i.e. iterative, processes but does not represent a sequential process. Often there are sequential activities within the iterative process but that is not a problem since they are in a loop and will be repeated. What
Figure 35  The two matrices of the work transformation model (WTM).
may be a problem though is an activity that is only performed after a sub-process has converged, e.g. continue after accepted review. In that case the matrix has to be divided into sub-matrices. The calculated TPT (see below) for the sub-processes are used as input to the W matrix for the main process.

It can be simulated, though not shown in this thesis, that this type of process, i.e. an iterative stage gate process, has a lower convergence rate and hence a longer total process time than a process where the review activities have been omitted.

Another assumption is that the matrix $A$ is static and linear. It does not change with time and there are no conditional relations. In a changing process, these are somewhat heavy assumptions and the WTM may not be reliable. Instead more general modelling techniques, such as signal flow graphs may be used, see e.g. Eppinger, Nukala and Whitney (1997) and Andersson, Pohl and Eppinger (1998).

Another, more fundamental, assumption is that there is no noise, i.e. no stochastic variation, in the process. To deal with that another approach has to be used, e.g. robust design (Phadke, 1989; Bergman 1992; Bergman and Klefsjö, 1994; Svensson, 1998).

5.2.5 Total Process Time; TPT

The work vector $u_n$ describes the amount of work done in each step $n$. The amount of work in the initial step is 1 for all activities, meaning that all activities are carried out once, thus $^{10}$:

$$u_0 = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \end{bmatrix}^T$$

Due to the work transformation, the amount of rework in the following iteration loop is:

$$u_{n+1} = Au_n$$

For a convergent process (see below), the total work vector is:

$$U = \sum_{i=0}^{\infty} u_i = \sum_{i=0}^{\infty} A^i u_0$$

10. The dimension is equal to the number of activities.
By introducing eigenvalue decomposition the infinite series can be solved exactly. Because the
eigenvector matrix is often ill-conditioned it may not give a robust solution. (For more details,
see Smith and Eppinger (1997). However, eigenvalue decomposition is introduced for another
purpose in section 5.2.8 ‘Identifying potential for improvement’. ) Instead, as was found in
practical applications, the series may be truncated after only very few iterations. The
simulations presented in this thesis (made with the software Matlab\textsuperscript{11} ) were often truncated
after ten iterations, satisfying a chosen convergence criterion.

The total work vector may be scaled with the actual duration of each activity, \textit{i.e.} the task times
in the diagonal matrix \(W\). Thus, the total process time vector \(WU\) is:

\[
WU = W \sum_{i=0}^{\infty} A^i u_0
\]

and the scalar total process time TPT is the sum of all elements in the total process time vector:

\[
TPT = \sum_{i=1}^{n} (WU)_i
\]

where \(n\) is the number of elements in the total process time vector \(WU\).

Notice that it is possible to calculate TPT exactly without numerical simulations by using
eigenvalue decomposition, but due to the problem of ill-conditioned matrices it is not described
further here except for the following special case.

In a simple process consisting of only two coupled activities, see figure 31c, the solution for the
total process time is:

\[
TPT = \frac{w_{11}(1+a_{12}) + w_{22}(1+a_{21})}{1 - a_{12}a_{21}}
\]

where \(w_{11}, w_{22}, a_{12}\) and \(a_{21}\) are the non-zero elements in the 2x2 matrices \(W\) and \(A\).

\textsuperscript{11}\textsuperscript{ Matlab, Trademark of The MathWorks Inc.}
5.2.6 Convergence of iterations

In the first iteration step all activities are fully carried out, i.e. they are done once ($u_0$ equals a vector of ones). The process time for the first step is the sum of the diagonal elements of $W$. The work increments will decrease in the following steps, i.e. if the process is convergent. A sufficient, but not necessary, criterion for convergence is that the entries in either every row or in every column of the transformation matrix $A$ sum to less than one. In the example in figure 35 this is true for all columns but not for the rows. As can be seen in figure 38 on page 92 the process in the example is convergent. After only ten iterations the TPT has reached a stable value (in this example, 15.9 time units). Iterations with very small changes near convergence are not performed in reality. Instead the process is often stopped after less than five iterations.

5.2.7 Simulated To-be / As-is Ratio; STAR

The calculated TPT is a measure of the total amount of time, i.e. effort, required for the process to converge. It has units of work (e.g. person-hours). However, TPT expressed as an absolute value is of somewhat limited value. Instead, TPT for the given as-is process and TPT for the changed to-be process are related. The change introduced to the process, e.g. a new software or a new work method, is a ‘small disturbance’ to the system. The process map stays the same but the numbers change. Hence the simulated to-be / as-is ratio (STAR) is a sensitivity measure of a suggested improvement as a linearization around an existing process.

$$\text{STAR} = \frac{TPT_{to-be}}{TPT_{as-is}}$$

(7)

STAR is a relative measure of the overall impact of a suggested process improvement.

5.2.8 Identifying potential for improvement

One question that emerges is which improvements to suggest. There may have been several suggestions already before the process map was developed and those could of course be examined, but there is another way to find out where potential improvements could have most effect.

---

12. To deal with calendar time instead of effort, Smith and Eppinger use modified equations (Smith and Eppinger, 1998).
Each eigenvalue of the transformation matrix $A$ represents the convergence rate for one possible iteration mode in the process. Smith and Eppinger use the term ‘design mode’ instead of iteration mode. The iteration mode with the slowest convergence rate is identified by the largest eigenvalue which always is positive and real. (Smith and Eppinger, 1997). The eigenvalues and eigenvectors of $A$ is found by decomposing $A$ according to:

$$AV = VD$$

where $D$ is a diagonal matrix of the eigenvalues of $A$, and $V$ is the corresponding eigenvector matrix. Notice that it is not necessary to invert the eigenvector matrix which often is ill-conditioned (as mentioned in section 5.2.5 ‘Total Process Time; TPT’). The eigenvalues and eigenvectors presented in this thesis were easily solved by the use of Matlab.

The eigenvalues (the diagonal elements of $D$) and the first eigenvector (the column in $V$ corresponding to the largest eigenvalue) of $A$ for the iterative process in the example are given in figure 36. As can be seen, the largest eigenvalue is positive and real. Furthermore, the eigenvector associated with this eigenvalue have positive (and real) elements. Each of these elements characterizes the relative contribution of one activity each in the slowest converging iteration mode. The interpretation of the other eigenvalues with corresponding eigenvectors is somewhat uncertain and hence no more than the first mode is used in this thesis. (Smith and Eppinger present a more thorough interpretation, see Smith and Eppinger, 1997.)

The interpretation of the slowest converging iteration mode is that activity 5 has the largest contribution. Also, by looking at the task time matrix in $W$ (figure 35) we see that activity 5 has the longest task time. It is evident that, to reduce the total process time and hence get a lower STAR, we should concentrate on activity 5, its task times and its re-work fractions.

### 5.2.9 Comparisons of suggested improvements

Two different improvements are suggested, see figure 37. Both focus on activity 5. Improvement #1 is a make-less-iterations improvement, e.g. better interface to activity 5. All numbers in row 5 and in column 5 of the $A$ matrix have been divided by two. Improvement #2 is a work-faster improvement, e.g. faster tools for activity 5, hence the task time for activity 5 in the $W$ matrix has been divided by two.

In figure 38 the TPT, the $U$ vector (total work vector) and the $WU$ vector (total process time vector) after ten iterations are given.
In the left part of the figure the TPT, $U$ and $WU$ are given for the as-is process and for a suggested improvement #1. In the right part the as-is process is compared to suggested improvement #2.

For the make-less-iterations improvement the work as well as the amount of time decrease considerably for activities 2 and 5 and some also for 3, 4, and 6. The TPT after ten iterations is 10.1 time units and hence the STAR is $10.1 / 15.9 = 0.64$.

For the work-faster improvement the $U$ vector stays unchanged but the TPT decreases because the total work carried out in activity 5 decreases, giving a TPT = 12.9 time units and a STAR = $12.9 / 15.9 = 0.81$.

One of the most interesting things to notice is that improvement #1, in addition to giving a lower STAR, also gives a much faster convergence than the as-is process and improvement #2. Look especially at the time/iteration curves (lower curves) in figure 38. The number of necessary iterations decrease by half.

Figure 36  Eigenvalues and first eigenvector of $A$. 

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90
Suggested improvement #1
“Less iterations”
(Better interface to activity 5)

A : transformation matrix

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Suggested improvement #2
“Work faster”
(Faster tools for activity 5)

W : task time matrix

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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 37 Two different improvement suggestions.
Figure 38  Simulation results from two different suggested process improvements
(as-is: dark bars at back; improvements: lighter bars in front).
In reality, the most successful improvements are combinations of fewer iterations and working faster. A combination of the two improvements in this example, i.e. to use both the new A matrix and the new W matrix, would shorten the TPT even more, giving a STAR = 0.54, i.e. a total time reduction of 46%.

The Matlab files used for the example are given in appendix 1.

5.3 APPLICATION OF PROCESS IMPROVEMENT SIMULATIONS TO A GAS TURBINE BLADE DEVELOPMENT PROCESS

In this section I describe an application of the method, described in the previous section, to a gas turbine blade development process at ABB STAL. Among the most critical parts in a gas turbine are the blades. Due to the extreme technical demands on gas turbine blades, the development of the blades is a very complicated, coupled process. It includes several specialists from several technical domains. In an effort to achieve increased integration, a project was launched at ABB STAL with the mission of mapping the as-is process and to suggest improvements in a to-be process map for gas turbine blade development.

5.3.1 As-is process map

The as-is process map (figure 39), was developed over several months by a small project team, consisting of seven engineers normally working with gas turbine blade development. I was one of them. The main process consisted of three sub-processes: aerodynamic design, mechanical design and verifying mechanical integrity. The main reason for this division was that the activities of those sub-processes were carried out by engineers from different departments with names similar to those of the sub-processes. By looking at the map in figure 39 it is obvious that the activities and the sub-processes are highly coupled. Hence the map was transformed to a DSM (figure 40). Also, a task-time matrix W and a transformation matrix A for the as-is process were created, but since the numbers are not for public display, only the DSM is shown in this thesis.
1. Acquire Turbine specification
2. Aerodynamic design. Acquisition of initial geometry.
3. Aerodynamic design. Flow path design. Selection of design points.
15. Mechanical design. Acquisition of model data. Geometry.
16. Mechanical design. Acquisition of model data. Material properties.
17. Mechanical design. Acquisition of model data. Manufacturing restrictions.
18. Mechanical design. Acquisition of model data. Design restrictions.
32. Verifying mechanical integrity. Acquisition of data for modelling. Loads.
33. Verifying mechanical integrity. Acquisition of data for modelling. Material properties.
34. Verifying mechanical integrity. Modelling. Transform geometry data to model.
37. Verifying mechanical integrity. Modelling. Apply material properties.
42. Verifying mechanical integrity. Evaluation. Design criteria, static.
44. Verifying mechanical integrity. Evaluation. Comparisons with tests.
46. Deliver performance data.
47. Deliver blade design documentation.
48. Deliver Acquisition specifications.
49. Deliver Manufacturing specifications.

Figure 39  As-is Process map for the gas turbine blade development process (courtesy of ABB STAL 1997).
Only a short while after the process team had begun working with the as-is map, they discovered things that could be improved. Even though those suggested improvements often were obvious and easy to fix they had not been suggested earlier since they dealt with matters that had fallen between the responsibilities of the different departments. Some of these improvements were implemented at once, since there was no reason to wait if it easily could improve the process.

Other process improvements that were suggested from looking at the as-is map were more extensive and could not be implemented at once because the project group did not have the authority to implement them. Such improvement suggestions were e.g. change of CAD/CAE software and earlier manufacturing involvement.

**Figure 40 DSM for the blade development process. Numbers in A and W matrices are indicated by marks (not for public viewing)**

**5.3.2 Simulations of suggested improvements**

Only a short while after the process team had begun working with the as-is map, they discovered things that could be improved. Even though those suggested improvements often were obvious and easy to fix they had not been suggested earlier since they dealt with matters that had fallen between the responsibilities of the different departments. Some of these improvements were implemented at once, since there was no reason to wait if it easily could improve the process.

Other process improvements that were suggested from looking at the as-is map were more extensive and could not be implemented at once because the project group did not have the authority to implement them. Such improvement suggestions were e.g. change of CAD/CAE software and earlier manufacturing involvement.
The discussion on choice of a common CAD/CAE software had been going on for a while. The stress engineers claimed that if the mechanical designers and the stress engineers used a common CAD/CAE software utilizing parameterized geometry (the one that the stress engineers already used for finite element pre- and post-processing) it would shorten the development time considerably. People in other departments thought other aspects of the choice of CAD/CAE software were more important and did not really think that the stress engineers should have opinions on the tools within mechanical design.

An analysis of the slowest converging iteration mode, identified from the highest eigenvalue and the corresponding eigenvector of the matrix showed that the iteration mode consisted of activities mainly within Mechanical Integrity and some within Mechanical Design (see figure 41). This supported the suggestion of a common CAD/CAE software for these two domains. Therefore, a study was made with the purpose of measuring the task times and re-work fractions for finite element modelling for different CAD/CAE software combinations at the departments.

Figure 41  Eigenvalues and first eigenvector of A. for the Blade Development Process
Different CAD/CAE software (not parameterized geometry)

As-is process.
Different CAD/CAE software (not parameterized geometry)

Create first FE model ($w_{ij}$)

Update blade geometry

Ratio ($a_{ij}$)

To-be process.
Common CAD/CAE software (parameterized geometry)

<table>
<thead>
<tr>
<th>Modelling time for different processes</th>
<th>Create first FE model ($w_{ij}$) [time units]</th>
<th>Updating blade geometry [time units]</th>
<th>Ratio ($a_{ij}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-is process. Different CAD/CAE software (not parameterized geometry)</td>
<td>80</td>
<td>56</td>
<td>0.70</td>
</tr>
<tr>
<td>To-be process. Common CAD/CAE software (parameterized geometry)</td>
<td>20</td>
<td>1</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Table 14 Results from study of blade modeling times.

Figure 42 Improvement suggestion: Common CAD/CAE software
Figure 43  Simulation results from the suggested process improvement: common CAD/CAE software.
The results from the study, given in table 14, were implemented in the A and W matrices (see figure 42) and used for TPT calculations. Results from simulations showed that the simulated to-be process, compared to the as-is process, has STAR=0.83 (see table 15), i.e. the overall development time for the gas turbine blades would decrease by 17% by switching the CAD/CAE software of the mechanical design department. By inspecting the total work vectors in figure 43, we notice that the amount of work decreases considerably for the stress engineers within the mechanical integrity process (activities 31-45) but not that much within the other two sub-processes. There were also opinions that the new software was a better CAD software and hence the total work in the mechanical design process would decrease. Furthermore, the use of common geometry models would increase the cross-disciplinary cooperation, but none of those matters have been taken into account here. Only new task times and re-work fractions for finite element modelling have been included in the simulation. Still, 17% of the total person-hours for such a development project is a lot of money, hence the company decided to make the suggested investment.

Installing the common CAD/CAE software for the gas turbine development team led to many problems, as one could expect. To change the team software they also had to adapt the process. After some months the people had adapted to the new software and the simulated improvements were realized. The stress engineers confirmed the to-be FE modelling times from the study and the engineers in the team thought that the iterations had become faster.

It is not quantitatively proven that the faster iterations were actually making the process time shorter. Since the engineers are in the middle of the process, there is no way for them to measure the new total process time. Qualitatively though, the engineers expressed in discussions that “things got finished faster”.

<table>
<thead>
<tr>
<th>Suggested improvement</th>
<th>TPT_{to-be} [time units]</th>
<th>TPT_{as-is} [time units]</th>
<th>STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common CAD/CAE software</td>
<td>193</td>
<td>231</td>
<td>0.83</td>
</tr>
</tbody>
</table>

Table 15  STAR for suggested improvement: common CAD/CAE software.
5.4 DISCUSSION AND CONCLUSION

Task based DSM is one of very few tools for mapping and visualizing iterative processes. From a DSM is easy to get a holistic view of a complex development process where flow charts become too complicated.

In this method processes are studied at a very detailed level. WTM and the newly presented concept STAR are easy to use for process improvement simulations. The assumptions made in the method are linearity and stability of the process and fully parallel task execution. The parallel assumption may look severe, but as was found in practical applications, that has a small influence on the final results given as TPT and STAR. If one sub-iteration is converging fast and another sub-iteration is converging slowly, the process does not converge until the slow iteration has converged. Then the activities in the fast sub-iteration have been executed several times with ‘close-to-zero’ re-work. That may look strange but does not change the final result expressed as TPT and STAR. If these assumptions correspond to the actual process the output provides good guidance for further process development and improvement.

One should not forget though, that the method demands a detailed process map. One could argue that the main process improvements come from the knowledge gained from the process mapping itself, i.e. once the map exists the suggestions for improvements become obvious.

On the other hand, it is my experience from process development that it is difficult to get the authority to implement major changes in an organization if one cannot show some estimate of the payback on the investment.

The simulated to-be as-is ratio STAR is such an estimate, since it quantifies the impact from a suggested improvement on the overall process performance, expressed as reduction of total process time. Hence, it is a good tool for speeding up iterations, i.e. the ‘middle path’ in the Engineering Management Model.

In the following chapter we move down to the bottom of the Engineering Management Model. The question is: Now that we are working together in a fast process, with common goals and visions, what can we do to improve understanding and reduce misunderstandings between engineers?
CHAPTER 6

KNOWLEDGE OVERLAPPING SEMINARS

The experience leading to the research for this chapter started in 1984 when I started to gain experience with specialized engineering domains at my work at SAAB. Many years later, at ABB STAL in 1999, I had the possibility to scientifically and operationally design and test a new communication method for engineers in a product development team with the purpose of reducing misunderstandings. Prior to this thesis the results have only been published in interim reports.

6.1 INTRODUCTION

In this chapter a method called Knowledge Overlapping Seminars (KOS) is described. It is a method for engineers to talk to one another about their domain-specific knowledge in a new way. The method is one possible solution to my first research question RQ1 ‘How can understanding between engineers from different backgrounds in a product development organization be improved?’ The purpose is to achieve redundancy, something that obstacles in ‘ordinary’ meetings and seminars prevent, and hence to eliminate misunderstandings due to lack of redundancy. I also present results from applications of six KOS to a gas turbine development team.
6.2 CONCEPTS AND THEORY OF KNOWLEDGE OVERLAPPING

In this section I first explore the conditions that exist in ‘ordinary’ project meetings and what is preventing creation of redundancy. Next I present the Knowledge Overlapping Seminar as a method to create redundancy in a project team.

6.2.1 The need for knowledge overlapping

Senge identifies mental models as an important ‘discipline’ of a learning organization. “The discipline of working with mental models [...] includes the ability to carry on learningful conversations [...] where people expose their own thinking effectively and make that thinking open to the influence of others” (Senge, 1990, p.9).

Nonaka and Takeuchi examine Senge’s five disciplines and conclude that the disciplines have some affinity with what they call knowledge creation but Senge “... rarely uses the word ‘knowledge’ and does not present any ideas on how knowledge can be created”. (Nonaka and Takeuchi, 1995, p.45).

From what I understand, Senge’s discipline of ‘carrying on learningful conversations’ is a way to ‘build redundancy in an organization’, something that Nonaka identifies as an organization-wide enabling condition that promotes knowledge creation, but I agree that Senge does not present any ideas, i.e. any method, to build redundancy.

To understand the difficulties in building redundancy in a product development organization, we turn to Tom Allen. Allen identifies prestige as the major obstacle. “An engineer’s prestige among his colleagues is founded to a great degree upon an almost mystical characteristic called ‘technical competence’. To admit a lack of technical competence, especially in an area central to the engineer’s technological speciality, is to pay a terrible price in terms of lost prestige.” (Allen, 1977, p.193)

I have seen this phenomenon many times during my fifteen years of work at SAAB and ABB STAL. To be successful, a method that is designed to create redundancy has to facilitate elimination of prestige.
As mentioned in section 3.3.3 ‘Knowledge management’ Allen and Nonaka present strategic rotation, i.e. to move people around at departments, as a way to build redundancy in an organization. From my experience, rotation is a way to share mental models in the long term. At ABB STAL rotation between different departments is quite common and career paths go zig-zag between departments as well as up and down in the organization, unlike SAAB where engineers tend to stay at one department and possibly make a career upwards in the organization. When I compare the two organizations I see more willingness to share mental models at ABB STAL than at SAAB. The disadvantage of rotation of people is of course that it takes time and too much rotation does not allow people to get skilled in a certain task. My boss - one of the most experienced engineers and project managers at ABB STAL for whom I have high regard - once told me at the coffee table “The entropy is increasing at every re-organization”\(^\text{13}\). We all laughed and started to discuss how the entropy increases when the walls are removed in the box, i.e. the company, and are replaced by new walls, i.e. new departments. By then all gas molecules, i.e. engineers, are totally mixed. This metaphor shows that redundancy can be seen as disorder. We need more disorder if we are to get knowledge overlapping. But disorder also means disturbance to people who constantly must learn new tasks.

There is a need for a method that quickly increases redundancy within a project team with members from different knowledge domains without constantly re-defining their tasks. What we need is some kind of meeting or seminar where the engineers in the team teach one another domain-specific knowledge. The condition to strive for is where the team members know enough about other domains to realize when their actions are creating or may create problems in other areas.

Allen suggests that “seminars that included engineers from several projects and functional areas could be organized around topics so that all participants would appear as equals” (Allen, 1977, p. 200) and “periodic seminars organized around specific problem areas or specific technologies in which management feels that the laboratory has particular competence hold great promise for improving the flow of information between technical specialists and project members” (Allen, 1977, p. 201). This is very close to the experience and proposal within my research work.

\(^\text{13}\) The definition of entropy is the degree of disorder or uncertainty in a system, a central concept in thermodynamics.
6.2.2 Obstacles for creating redundancy in ‘ordinary’ meetings

What is preventing us from creating redundancy in ‘ordinary’ meetings and seminars? Davenport and Prusak (1998) present a list of common ‘frictions’ that prevent knowledge transfer, see table 16 below.

I will briefly describe the obstacles for creating redundancy in different kinds of meetings and seminars *that I have seen* during several years in product developing organizations (see table 17 and the following text). As you will see, several ‘obstacles’ can be found as ‘frictions’ in Davenport and Prusak’s list.

In the next section I will describe the Knowledge Overlapping Seminar where these obstacles are avoided, partly by using the possible solutions presented by Davenport and Prusak.

<table>
<thead>
<tr>
<th>Friction</th>
<th>Possible Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of trust.</td>
<td>Build relationships and trust through face-to-face meetings.</td>
</tr>
<tr>
<td>Different cultures, vocabularies, frames of reference.</td>
<td>Create common ground through education, discussion, publications, teaming, job rotation.</td>
</tr>
<tr>
<td>Lack of time and meeting places; narrow idea of productive work.</td>
<td>Establish time and places for knowledge transfers: fairs, talk rooms, conference reports.</td>
</tr>
<tr>
<td>Status and rewards go to knowledge owners</td>
<td>Evaluate performance and provide incentives based on sharing.</td>
</tr>
<tr>
<td>Lack of absorptive capacity in recipients.</td>
<td>Educate employees for flexibility; provide time for learning; hire for openness to ideas.</td>
</tr>
<tr>
<td>Belief that knowledge is prerogative of particular groups, not-invented-here syndrome.</td>
<td>Encourage nonhierarchical approach to knowledge; quality of ideas more important than status of source.</td>
</tr>
<tr>
<td>Intolerance for mistakes or need for help.</td>
<td>Accept and reward creative errors and collaboration; no loss of status from not knowing everything.</td>
</tr>
</tbody>
</table>

Table 16 Frictions that prevent knowledge transfer (Davenport and Prusak, 1998).
<table>
<thead>
<tr>
<th>Obstacles for creating redundancy</th>
<th>Type of meeting or seminar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profound knowledge is not a socially accepted topic</td>
<td>Talking at the coffee machine</td>
</tr>
<tr>
<td>There is no time to ask questions about profound knowledge.</td>
<td>STOP</td>
</tr>
<tr>
<td>Detailed discussions between two people are not allowed.</td>
<td>STOP</td>
</tr>
<tr>
<td>There is a big risk for loss of prestige by asking a ‘silly’ question.</td>
<td>STOP</td>
</tr>
<tr>
<td>Defending the domain</td>
<td>STOP</td>
</tr>
<tr>
<td>Knowledge is not discussed, only concrete and abstract concepts</td>
<td>STOP</td>
</tr>
<tr>
<td>Profound knowledge about other domains does not connect to specific tasks</td>
<td>STOP</td>
</tr>
<tr>
<td>Profound knowledge does not connect to knowledge of other domains</td>
<td>STOP</td>
</tr>
<tr>
<td>none of the above</td>
<td></td>
</tr>
</tbody>
</table>

Table 17  My experience of obstacles for creating redundancy that occur in different kinds of meetings and seminars. A symbolic picture, see text for details.

* KOS = Knowledge Overlapping Seminar
Talking at the coffee machine

The coffee machine or the coffee table is a common meeting place for Swedish engineers where the latest information is always available. Engineers from different domains within a project team meet and discuss the weather, last night’s TV show or something else that is socially accepted. Profound knowledge is not a socially accepted topic. If two engineers, both from the same domain, still start to talk about something domain-specific the engineers of other domains automatically turn away and start to talk about something else. The communication between domains at the coffee machine consists of concrete concepts and superficial knowledge which do not contribute to creation of redundancy. Going out to a bar together is the same kind of meeting as sitting around the coffee table.

Project meeting

There are several types of project meetings. Below I have listed three that I think are most common. The column ‘project meeting’ in table 17 is a compilation of these different types of meetings.

First, a project work meeting is a meeting where engineers from different domains discuss a specific problem. The goal is to solve the problem together. In this type of meeting it is common that engineers discuss the matters that are connected to their own specific tasks and use several ‘keywords’ to describe the task. Engineers from other domains quickly learn these keywords but do not really understand what they mean. What is discussed is superficial knowledge and concrete tasks. There is no time to ask questions about profound knowledge. A detailed discussion between two people from the same domain, excluding the rest of the participants from the discussion, is usually not allowed to allocate a large fraction of the time available for the meeting. The project manager usually asks the two to continue the discussion after the meeting.

Second, a project coordination meeting is a meeting where tasks are coordinated usually to a time schedule. Knowledge is not discussed, only concrete tasks and abstract goals like e.g. dead-lines etc.

Third, a project presentation meeting is a meeting where one engineer presents to the other members of the team some aspects of a specific task that he/she is working on. If an engineer of another domain asks a ‘silly’ question the engineers of the same domain as the presenter will
smile and make ‘silly’ answers. They do not have the intention of humiliating the engineer who asked the ‘silly’ question but that is effectively what they do. I have seen this happen many times. The engineer who put the question loses prestige and will probably not make the same mistake again. On the other hand, if an engineer asks a ‘critical’ question the same engineers will now turn into one firm hand and protect the domain. “We know what we are doing.”

Process meeting

A process development meeting resembles a project coordination meeting. It is not at all as defensive as a project presentation or work meeting. What is discussed is not how a problem should be solved but how the problem solving process should look. There is not as much prestige and domain defending involved. Some engineers who are unfamiliar with the environment of a process meeting may feel uncomfortable with the fact that the domain identity is not very important. Once they relax they usually think that it is very nice to be able to talk to engineers of other domains about a common goal without the obstacle of prestige. Unfortunately, knowledge is not discussed, only concrete and abstract concepts.

In-house course

By an in-house course I mean an introductory course about some technical domains that are especially important for the company. It is usually taught to junior engineers. At SAAB it is called ‘Flygplansbyggnad’ (‘Aircraft design’) and at ABB STAL it is called ‘Turbinteknisk grundkurs’ (‘Introduction to turbine technology’). These in-house courses may be good as broad introductions for newly employed engineers but there is one obstacle that prevents redundancy. Even though some of the lessons may go quite deep down in domain-specific knowledge, usually they do not connect to the specific tasks that the pupils are working on. “Interesting lesson but now I have to catch up with my ordinary work”. Unfortunately the profound knowledge about other domains does not connect to specific tasks.

University course

It is unusual that an engineer of one domain is sent to a university course about another domain. If it happens, the initiative is often from the employee, not from management. On the other hand it is quite common that an engineer attends a university course about his own domain to deepen his own domain knowledge. At least in Sweden, this is seen as a reward for doing a good job. Being sent to a course on another domain may be seen as some kind of criticism. “Maybe you
should be doing something else.” This is very unfortunate since it decreases redundancy in the organization. The profound knowledge gained at a university course does not connect to knowledge of other domains.

6.2.3 The Knowledge Overlapping Seminar

For the purpose of creating redundancy I propose a method called Knowledge Overlapping Seminars (KOS). It is designed for creating redundancy but to avoid the obstacles that occur in different kinds of meetings and seminars as described above.

**Objective**

The main objective for a KOS is to stimulate engineers within a project group to talk about profound knowledge. The second objective is that they should actually learn something about another domain. Notice the order of priority. Of course it is a benefit if they learn something new but the time for a KOS is too short to actually learn a lot. Instead it is more important for the participants to learn to talk to one another in such a way that they can continue to learn also after the KOS.

**Preparations by the team**

First of all the project team, consisting of engineers from different domains, gathers and discuss “What is our common task?” In this meeting, and in the following meetings, it is useful to use ‘the diamond’, i.e. the Engineering Management Model described in figure 11 on page 46. ‘Our common task’ is an abstract concept in the top of the model. It should be something that all members can relate to as our and my task. It is not enough that most members accept it. The common task should be as abstract as necessary to include all members’ specific tasks. Even though the project group may be functioning very well it is not sure that they have a truly common task. This is an important first step towards KOS and it may take a while.

Second, two or three domains should be identified. These may be e.g. Mechanical design and Electrical design. Two domains give two KOS, three domains give six KOS and so on \(14\). The domains should be chosen to include as many team members as possible. One domain should

\[ n = d(d - 1) \]

where \(n\) is number of KOS and \(d\) is number of domains.
be represented by at least two people, preferably by three to five people, and not more than eight people.

Third, one of the members of each domain should be appointed ‘teacher’. The teacher does not need to be the engineer with the most specialized knowledge within the domain. It is better if he/she is not a ‘specialist’. The teacher needs to:

- be a good educator,
- find it easy to talk and to listen, and
- understand that everybody does not understand “self-evident facts.”

**Preparations by the teacher**

The teacher, i.e. one from each domain, prepares his/her KOS alone or possibly together with a neutral seminar facilitator (not a member of any of the chosen domains). An estimation of the total time for preparations is one working day, i.e. eight working hours.

Steps in the preparatory work:

The teacher starts by describing one specific concrete task that his/her domain is responsible for as a part of the common abstract task. E.g. a stress engineer may describe his/her task as “to calculate stress and strain we use the software Abaqus”. This is superficial knowledge, i.e. answers on ‘what’ and ‘how’ that most engineers in the team already know about. There is no need to describe this thoroughly. Estimate that this point will need approximately ten minutes presentation at the KOS.

Then the teacher asks himself/herself “why do we have to do that?” or “why is this important?” or any other ‘why’ question. Some questions the teacher may find easy to answer, e.g. “why do we have to calculate stress, by the way, what is stress?” but other questions may be harder to answer, e.g. “why do we use a certain evaluation criterion?”. The questions that are most difficult to answer often address tacit knowledge. The teacher has to transform his own tacit knowledge to his own explicit knowledge to be able to express it to others, giving them explicit knowledge which they hopefully can transform into tacit knowledge. This is Nonaka’s knowledge spiral, see section 3.2.3 ‘Knowledge dimension’.

The teacher continues to ask ‘why’ several times - compare to ‘Toyota’s five whys’ (Ohno, 1988) - until he/she has reached down to profound knowledge. There may be several ways down and the teacher selects those that he/she thinks are important. It is not necessary or possible to
cover all ways down. The way down to profound knowledge is domain-specific knowledge - tacit and explicit knowledge - to which engineers outside the domain have no access. The profound knowledge often contains patterns and relations between more superficial knowledge which engineers from other domains may already possess, but they do not yet see the patterns. This superficial knowledge can be e.g. classical physics or something else that engineers from different domains share from a common education. When the teacher explains the patterns in a KOS, the engineers from other domains will see new relations to their own profound knowledge, since they can relate to a common task. Knowledge overlapping is built from both sides, the teacher explains and the listeners interpret and see new patterns.

The most important thing in the preparations is for the teacher to think “why am I doing what I am doing?”. In the KOS however, most of the questions from the participants will be on things that the teacher did not prepare for. These will be ‘easy’ questions.

**The seminar.**

The participants in the seminar should be one teacher from one domain (A) and pupils from another domain (B). There should also be a neutral seminar leader present. The seminar leader should not act as a member of any of the domains but should stimulate the participants to ask ‘silly’ questions.

It is very important to follow these rules, otherwise obstacles for creating redundancy will occur. I will describe why.

No more engineers from the teacher’s domain (A) are allowed in the seminar. Otherwise this would lead to:

- Unnecessarily detailed discussions between the teacher and the other ‘A engineer’ which would lead to the ‘B engineers’ starting to think about something else and would prevent them from asking ‘silly’ questions with the risk of losing prestige.
- The teacher would become nervous because he/she is trying to express things that maybe an ‘expert’ from A may have other opinions about.

All participants except for the teacher have to be from the same domain. If there are three domains in the team (A, B, C) the teacher has to hold two KOS, one for B and one for C. If the pupils were from two domains the risk of lost prestige would appear again because some may think that questions from the others are silly.
The seminar leader controls the seminar. The seminar should start at the top of ‘the diamond’ (figure 11 on page 46) with the common task. The teacher then briefly describes his/her specific task in the project and then goes deeper into the model talking about why he/she has to do that. There should be a dialogue between the teacher and the pupils. One of the responsibilities of the seminar leader is to continuously check that everybody understands every step down in the domain knowledge. It is common that the teacher tries to explain something that he/she thinks is unknown or difficult and starts too deep. E.g. the teacher says “OK, now I am going to explain a stress-strain chart.” and the seminar leader interrupts and asks the pupils “Does each one of you know what stress is?” Some of the pupils say no and the teacher has to explain something that he/she did not prepare for. It is usually no problem for the teacher since it is something that he/she knows very well and can draw the definition on the board. For some of the pupils this is news, even though they and the teacher usually are fellow-workers. Some redundancy has been created.

Measurement

There are several levels of possible measurements of the effect of a KOS. It would be nice if one could measure the time and cost spent by the team on KOS and compare it to the possible reduction of time and cost spent on late changes due to misunderstandings. One way to do that would be to measure the effect on process performance by use of the process simulation method described in chapter 5 ‘Process Improvement Simulations’. It is possible if one has a detailed process map and can estimate how the re-work fractions and task times change due to a KOS. I still think it may be difficult since a KOS does not directly change any computer programs, databases or work methods. What changes is the awareness of other domains and the way engineers talk to one another. It may be difficult - but not impossible - to translate that directly into task times or re-work fractions.

What change quickly - not after several months - are the attitudes and opinions of the people involved in the KOS. If one assumes that a changed - improved - opinion towards other domains leads to better co-operation and hence better process performance, then an investigation of changes in opinions should be an effective measurement. I have made that assumption based on my own experience and on the words by Tom Allen, “It is astonishing to learn how generally ignorant the average member of an R&D laboratory is of work going on around him. Simply increasing the general awareness among members of what is going on in the laboratory is almost certain to enhance overall performance in the long run.” (Allen, 1977, p. 201). From my
experience at ABB STAL (see section 6.3) I found that the use of questionnaires to investigate the changes in opinions is a good qualitative measurement. For a more quantitative measurement process simulations could be used.

All participants including the teacher should answer a number of questions in a questionnaire three times: directly before the KOS, directly after the KOS and approximately one month after the KOS. I have also conducted semi-structured interviews with all participants to investigate how their opinions have changed. The results of the analysis are given in section 6.3. These results are of course research results. To use KOS outside a research context, just as a method to improve redundancy in a project, it is not necessary to make such thorough investigation. Evaluation of questionnaires should be enough. The questionnaires and analysis models used are given in appendices.

**When should KOS be arranged?**

My suggestion has been to arrange KOS in the beginning of a project and once per year for long projects. However, participants in KOS at ABB STAL suggested that they should be arranged more often (see section 6.3).

**What is new with KOS?**

As can be seen in the table 17 on page 105, KOS are designed to create redundancy but to avoid the obstacles in ‘ordinary’ meetings. But what also can be seen in the table is that most types of meetings or seminars only have one stop sign. They are actually not very bad if we eliminate the stop signs, i.e the obstacles. KOS is a synthesis of these types of meetings and seminars and also some other methods indicated below.

The most important differences from ‘ordinary’ meetings are:

- In KOS the topics always relate directly to the current common task. New knowledge is always connected to the problem that the receiver is working on right now. *This aspect of KOS has similarities to Problem-based learning (Egidius and Henry, 1991) and to Allen's seminars mentioned in section 6.2.1.*

- In KOS profound knowledge of other domains is discussed. In ordinary project meetings there are several obstacles for that, as seen above. Of course profound knowledge is discussed in ‘closed’ one-domain meetings but that does not create any redundancy.
• In KOS the pupils can ask ‘silly’ questions without losing prestige because they are alone with the teacher. KOS is a type of dialogue (in the meaning of Senge, 1990) while ordinary meetings often are discussions. This aspect of KOS has some similarities with Dialogue seminars (Wilhelmson, 1998; Hammarén, 1999)

6.3 APPLICATION OF KNOWLEDGE OVERLAPPING SEMINARS TO A GAS TURBINE DEVELOPMENT TEAM

In this section I will present results from six KOS in a gas turbine development team at ABB STAL.

6.3.1 The gas turbine development team

In the spring of 1999 I had several discussions with leaders at ABB STAL before we agreed on a project to be the pilot team in testing KOS. I had suggested a team in the company’s largest gas turbine development project but I was told that there was no time for KOS in that project. Instead we finally agreed on a smaller gas turbine development team in a project called GT35C Marine.

The project team was a task force for re-designing the compressor turbine in the marine application of the gas turbine GT35C. The project was started at the end of 1998 after some problems with rotating stall in the compressor turbine which had led to an accident when blades and guide vanes had fractured. The team had an action plan that was made after consultation with a shipping company, i.e. the customer, and a maritime classification society, i.e. the quality certifier.

The project consisted of one formal project manager, one operative project manager and approximately 20 engineers from different disciplines. The formal project manager was responsible for customer relations and the operative project manager was working as a mechanical designer in the team. The engineers in the team came from the disciplines mechanical design, aerodynamic design (i.e. fluid dynamics and thermodynamics, performance, combustion and cooling), mechanical integrity (i.e. analyses of strength of materials against structural dynamic vibrations, centrifugal loads and thermodynamic loads),
manufacturing, electrical control systems, testing and service. Not every engineer had been a
member of the team all the time, some had started just recently. Two of the mechanical
designers - consultants - had left the team and the company.

In discussions with the operative project manager three major knowledge domains were
selected, mechanical design (MECH), aerodynamic design (AERO) and mechanical integrity
(MIT). Four engineers from each domain were selected to participate in KOS. The operative
project manager was one of the engineers of the mechanical design domain. Three domains
meant six KOS: MECH ↔ AERO, MECH ↔ MIT, AERO ↔ MECH, AERO ↔ MIT,
MIT ↔ MECH and MIT ↔ AERO (meaning: Teacher’s domain ↔ Other participants’
domain).

6.3.2 Common task and selection of teachers

Common task

In the first meeting nine of the twelve engineers participated. After I had presented the concepts
of KOS (see presentation slides in appendix 2) the team started to discuss the common task. It
was not obvious what the common task was. One MIT engineer suggested ‘low cycle fatigue
analysis of a rotor disc’ but when I asked the engineers from the AERO domain if that was what
they were doing they did not agree. They suggested ‘improvement of cooling flows and
calculation of heat transfer coefficients’. I suggested that they should try to state a task that all
participants could agree upon, something abstract and common located in the top of the
‘diamond’ (in the presentation slides, also in figure 11 on page 46). After some not very serious
suggestions the team agreed upon “To re-design the GT35C compressor turbine for marine
application”. It was quite evident that the participants felt that this discussion was very valuable
- which was later confirmed in interviews.

Selection of teachers

Then it was time to select teachers, one from each domain. None of the participants volunteered
but after some discussion three engineers agreed to take on the job. The teachers from MIT and
AERO were Swedish engineers with some five years experience within their domains. The
MECH teacher was Russian - working at ABB STAL for some years - with several years of
experience. None of the teachers had prior training in teaching.
Dates for the six seminars and for the teachers’ preparations were set, but as it turned out, these dates had to be changed several times to accommodate moving schedules of ‘more important’ project activities.

During the preparation of his presentation, the MIT teacher discussed the design and content of the presentation with me. I had the ability to suggest some improvements, e.g. that he should go deeper down in his domain knowledge instead of talking too much about concrete tasks. The other two teachers prepared their presentations on their own.

6.3.3 The six seminars

The six seminars are described briefly below. They are listed chronologically in the order they were executed during October 1999. All seminars were arranged in a seminar room in ‘the castle’, i.e. Finspång Manor House, built in 1668, now the headquarters of ABB STAL. The participants had to walk approximately one kilometre from their ordinary offices. Coffee and buns were served at the seminars.

KOS: MECH ➞ MIT

The teacher was from the Mechanical Design domain and the four pupils were from the Mechanical Integrity domain. The seminar was held in English, since the teacher did not speak Swedish fluently. This did not complicate the conversations since all participants were used to project meetings in English.

Analysis of questionnaires show that all participants think that they will have good use and benefit from the knowledge gained at this KOS. Many want to continue to have KOS within this project and also within other projects. Opinions directly after KOS were mostly very positive but in interviews one month after KOS all pupils but one thought that the knowledge presented was not deep enough, i.e. too superficial.

Items in the discussion:

Design specifications; Feed-back from MIT; Axial and radial displacements; Turbine component geometry; Manufacturing possibilities and tolerances; Mass of components ‘in reality’ vs. ‘in the drawing’; “The designer should hold it all together”; Continuing discussion on tolerances.
**KOS: AERO 🔄 MECH**

The teacher was from the Aerodynamic Design domain and the three pupils were from the Mechanical Design domain.

The teacher went from the top in the model - common abstract task - via a specific AERO task down to the bottom - profound knowledge of the AERO domain - very quickly. Since this KOS was from a ‘more theoretical’ domain (AERO) to a ‘more practical’ domain (MECH), I thought that maybe the teacher went *too* deep, but the pupils - mainly non-graduate engineers - did not mind listening to the equations of thermodynamics.

One major misunderstanding became obvious as the teacher discussed the relations between boundary layer thickness, guide vane angles, and thermodynamic performance. The mechanical designers had discussed a decrease in the number of guide vanes with a blade dynamics engineer but not with the aerodynamic designer even though they had met several times in ordinary meetings. Now they became aware of a restraint that they had not been aware of before. This resulted in some immediate work for the project members. No quantitative estimate of the gains of this new awareness has been made but the team members felt really comfortable with the fact that this revealed now. Otherwise it could have turned out to be a major - very expensive - problem later in the project.

Analysis of questionnaires showed that all participants think that they will have good use and benefit from the knowledge gained at this KOS.

**Items in the discussion:**

Requirements on temperatures and transients; Less thermoload or more cooling; Boundary layer theory; CFD - computerized fluid dynamics; LES - large eddy simulations; Euler and potential theory; Enthalpy diagrams; Aerodynamic design of compressors vs. turbines; Cooling and sealing.

**KOS: AERO 🔄 MIT**

The teacher was from the Aerodynamic Design domain and the four pupils were from the Mechanical Integrity domain.
Directly after the KOS, the seminar did not appear to have been completely successful. Surprisingly, since this KOS was between two ‘theoretical’ domains, some pupils thought that the new knowledge was too deep and the way down from superficial knowledge and concrete concepts was not described thoroughly enough. Even so, analysis of questionnaires shows that all participants think that they will have some use and benefit from the knowledge gained at this KOS. One month after the KOS most participants had a more positive opinion about the seminar and thought that this seminar was actually the better of the two that they attended. All but one thought that the other KOS (from MECH to MIT) consisted of knowledge that was too superficial and that the knowledge in this seminar was more profound, which was positive.

Much of the discussion dealt with boundary layers and the uncertainties in boundary layer calculations and hence the uncertainties in calculations of heat transfer coefficients alpha. Alpha is extremely important as input data to the very complex calculations that are performed within the MIT domain. The uncertainty in alpha was probably shocking to some or at least surprising to most of the participants. Maybe that explains some of the partly negative opinions directly after the KOS. In interviews after a month most participants say that it was very valuable to see the ‘big picture’.

*Items in the discussion:*
Requirements on temperatures and transients; Less thermolod or more cooling; Boundary layer theory; CFD - computerized fluid dynamics; LES - large eddy simulations; Quality estimations of alpha calculations; Optimal blade distance; Enthalpy diagrams; Aerodynamic design of compressors vs. turbines; Cooling and sealing.

*KOS: MIT ➔ AERO*

The teacher was from the Mechanical Integrity domain and the three pupils were from the Aerodynamic Design domain.

This seminar was very successful. Comments from the participants during and after the seminar was e.g. “Why have we not done this before?”, “I should have needed this many years ago when I started here” and “It can only become better if we use this way of working”. Analysis of questionnaires showed that all participants think that they will have good use and benefit from the knowledge gained at this KOS.
It was very well structured. The teacher started with some superficial knowledge and concrete concepts and then explained the way down to profound knowledge within the MIT domain. Less than half of the time was spent on prepared slides and the remaining time on answering questions that the teacher had not prepared for. The pupils got a completely new understanding of concepts like crack, strain, material data, high cycle fatigue, low cycle fatigue and blade dynamics. Especially the complexity in material data was thoroughly explained. Analogies to the complexity in turbulence models, something that was introduced in the KOS from AERO to MIT, were used several times.

*Items in the discussion:*
Task of MIT: LCF analysis of low pressure turbine; Creep; Low cycle fatigue (LCF); High cycle fatigue (HCF); Material models; Stress concentrations; Notch effect; Plasticity; Fracture mechanics; Fatigue analysis; Increased number of different cycles for GT35C in marine application; Haigh diagram; Campbell diagram; Neuber evaluation.

*KOS: MIT ➔ MECH*

The teacher was from the Mechanical Integrity domain and the four pupils were from the Mechanical Design domain.

This seminar started late because some of the pupils got caught in the workshop on the way to the seminar and had to deal with a problem there before they could continue to the seminar. Due to that and due to rather uninspired pupils with not many questions the teacher felt a little bit annoyed. In the second half of the seminar the atmosphere improved with more questions and discussions involving the pupils.

Analysis of questionnaires showed that most participants gained knowledge at this KOS that they will have some use and benefit from in the future. The pupils got a deeper understanding of MIT calculations and realized that “the computers do not do the job on their own”. A discussion about crack initialization and inspection intervals led to a new discussion on how the team should arrange inspections of blades. It was also suggested that KOS could be used when starting up the new ‘component groups’ within the R&D department.
Items in the discussion:
Task of MIT: LCF analysis of low pressure turbine; Creep; Flow rules; Low cycle fatigue (LCF); High cycle fatigue (HCF); Haigh diagram; Rotating stall; Crack initialization; Plasticity; Fracture mechanics; Fatigue analysis; Campbell diagram; Neuber evaluation.

KOS: MECH ➔ AERO

The teacher was from the Mechanical Design domain and the four pupils were from the Aerodynamic Design domain. The seminar was held in English, since the teacher did not speak Swedish fluently. One of the pupils later expressed in an interview that the use of English instead of Swedish prevented him from asking as much as he would have wanted. The others did not think it was a problem.

The seminar was very successful. Analysis of questionnaires directly after KOS showed that all participants thought that they will have some use and benefit from the knowledge gained at this KOS. One month after KOS three of four were sure that they will have some use and benefit from the knowledge gained at this KOS. Comments were mostly very positive, e.g. “it is extremely useful to talk to people and discover the necessary things you thought you knew but obviously did not”.

Especially the discussion on cold and warm geometry and also bearings and fittings gave some new insights.

Items in the discussion:
Design specifications; Axial and radial displacements; Cold and warm geometry; Tolerances; Sealing edge thickness; Attachments; Airfoil position on the platform and datum points; Trailing edge shape; Roughness.

6.3.4 Results from analyses of all questionnaires and semi-structured interviews

Results from comprehensive analyses of questionnaires for each separate KOS have been reported in interim reports not included in this thesis. A report on the results from analyses of all questionnaires and semi-structured interviews is given in appendix 5.
Results from analyses of questionnaires

Before, directly after, and one month after each KOS each participant was asked to fill out a questionnaire. The questionnaires are given in appendices 3 - 4. The response frequencies were 100% (N=29) before, 100% (N=29) directly after, and 76% (N=22) one month after KOS. A total of 80 questionnaires were evaluated. Notice that the questionnaires are not independent. There were only twelve engineers involved in KOS. What I intended to investigate was the changes in opinions due to KOS. Therefore each person-KOS combination generated three questionnaires. Furthermore, each pupil attended two KOS - those who also acted as teachers attended four KOS - which of course influenced one another. The opinion before the second KOS was influenced by the first KOS, even though they connected to two different domains. Since there are so few participants and so small groups it is not possible to decide in advance what measures to use. That is decided once the data from the questionnaires have been reviewed. The statistical results presented here are contextual. To generalize and get statistically significant numbers more KOS in different contexts have to be carried out.

Analysis of questionnaires before and directly after KOS shows that 45% of the participants had classified their knowledge as deeper after KOS than before. When asked after KOS, 36% of the participants thought that their knowledge had deepened (compared to 45% from before-after comparison). Also after KOS, 69% of the participants said that they had increased their knowledge. The reason why more said the knowledge had increased than that it had deepened were given as comments to the questionnaires. “I thought I had deep knowledge about the other domain. Now I know that it was superficial.” Altogether, 86% of the participants have gained new knowledge and/or deepened their knowledge about other domains.

Some questions concern the need for knowledge about other domains. 95% think that they need deep knowledge about the other domain. After KOS the fraction who need ‘quite a lot’ of deep knowledge have increased from 32% to 45%.

The engineers from one domain (A) were also asked about their opinions about how much ‘A knowledge’ the engineers within another domain (B) possessed. The analysis shows that the opinions about other engineers’ knowledge about another domain have hardly changed at all due to KOS.
Directly after KOS all participants thought, 45% of them were sure, that they would have good use and benefit from the knowledge gained at these KOS. One month after KOS the fraction who were sure had increased to 64%.

**Results from analyses of semi-structured interviews**

Semi-structured interviews were carried out approximately one month after the six seminars with ten of the twelve participants. The missing two were away on a business trip. The interviews took place in a conference room in the team members’ ordinary office building. One person at a time was interviewed for approximately half an hour each.

At the beginning five questions on a paper were shown to the interviewee, who then could speak freely on these questions, not necessarily in the order they were written on the paper. I repeated and summarized what the interviewee had said and if he agreed that that was in fact what he had said and meant, I put it down in writing under the corresponding question.

The questions were:

- What (if anything) has been positive with KOS?
- What (if anything) has been negative with KOS?
- How could KOS be improved?
- Do you have any suggestions how you should continue within the GT35C Marine project?
- Anything else that you want to put forward?

After the interviews, similar answers were grouped together. A summary of the answers is given below in table 18 (notice that the table continues on the following page). All answers from the interviews are given in appendix 5.
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>What has been positive with KOS?</td>
<td>Integration within the team. The formulation of the common task improved the integration within the team. It was further improved by the six seminars.</td>
</tr>
<tr>
<td></td>
<td>The possibility to ask questions. In ordinary meetings the team members do not ask questions because: 1) There is no time, 2) One does not want to ask ‘silly’ questions, and 3) One does not know what to ask. In KOS these obstacles were not present.</td>
</tr>
<tr>
<td></td>
<td>Two types of new knowledge. 1) Definitions of concepts and keywords have given the participants new knowledge. 2) A new awareness has led to a new holistic view. Most participants think both these types have been valuable.</td>
</tr>
<tr>
<td></td>
<td>Formulating one’s own domain knowledge. Everybody should formulate and express their own domain knowledge, not only teachers.</td>
</tr>
<tr>
<td></td>
<td>Number of participants. Most participants think the number of participants in a KOS should be around five or six, and not more than ten, if everybody should be able to ask questions and take part in the dialogue.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>What has been negative with KOS?</td>
<td>Different needs for profound knowledge. Most - but not all - participants think the knowledge of some KOS could have been deeper.</td>
</tr>
<tr>
<td></td>
<td>Person dependent. It is important that the team members know one another socially. Some thought that they did not.</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>How could KOS be improved?</td>
<td>Documentation. Many want some documentation from KOS, but realize that it can be hard to produce since much of the seminar is an un-structured dialogue. At least copies of the prepared slides could be handed out.</td>
</tr>
<tr>
<td></td>
<td>Preparations by the teacher. The teacher should stick to the ‘diamond’ and talk more about profound knowledge and less about superficial knowledge.</td>
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</tbody>
</table>

*Table 18   Summary of answers in semi-structured interviews*
Chapter 6 - Knowledge Overlapping Seminars

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have any suggestions how you should continue within the GT35C Marine project?</td>
<td>Suggestions for continuation of KOS within the project: 1) KOS should have been arranged earlier, 2) KOS should be arranged again in six months, and 3) Next KOS may start from a previous misunderstanding.</td>
</tr>
<tr>
<td></td>
<td>KOS in other projects. KOS should be a natural part of ordinary project management. All project managers should learn how to arrange KOS.</td>
</tr>
<tr>
<td></td>
<td>Change of behaviour. Some suggest new ways of working and communicating within the team and in bilateral meetings, inspired by KOS.</td>
</tr>
<tr>
<td></td>
<td>KOS in cross-disciplinary groups. Some suggest that KOS should be arranged in the new cross-disciplinary groups within the R&amp;D department.</td>
</tr>
<tr>
<td></td>
<td>KOS for profit. Some think that KOS is a good way to increase the profit of the company.</td>
</tr>
<tr>
<td>Anything else that you want to put forward?</td>
<td>Motivation. Involvement and participation without force from management is important if participants are to be motivated.</td>
</tr>
<tr>
<td></td>
<td>KOS in cross-disciplinary groups. Some suggest that KOS should be arranged in the new cross-disciplinary groups within the R&amp;D department.</td>
</tr>
<tr>
<td></td>
<td>Table 18 Summary of answers in semi-structured interviews</td>
</tr>
</tbody>
</table>

6.4 DISCUSSION AND CONCLUSION

Shared mental models constitute an important precondition for eliminating misunderstandings between project members from different knowledge domains. Shared mental models, located in the lower part of the Engineering Management Model developed in chapter 3, can be built with redundancy. Hence, there is a need for a knowledge management method that increases redundancy within a project team. For that purpose I propose the method Knowledge Overlapping Seminars (KOS). It is designed to create redundancy but to avoid the obstacles that occur in ‘ordinary’ project meetings and seminars. The main objective for a KOS is to teach engineers within a project group to talk about profound knowledge. The second objective is that they should actually learn something about another domain.

KOS has been tested in an application to a gas turbine development team at ABB STAL. The opinions towards other domains have been investigated, especially the changes in opinions due to KOS. Results are very positive. Questionnaires show that 86% of the participants have gained
new knowledge and/or deepened their knowledge about other domains. Directly after KOS all participants thought and 45% were sure that they would have good use and benefit from the knowledge gained at these KOS. One month after KOS the fraction who were sure had increased to 64%. Many wanted to continue arranging KOS within the project and also recommended that KOS should be arranged within other projects.

In interviews the participants confirmed that they could talk about profound knowledge in a KOS, something that several obstacles had prevented them from doing in their previous meetings in the project. Once they could talk in a ‘new’ way, they quickly gained new knowledge and insights which were appreciated and valuable.

Thanks to KOS, the participants became aware of several misunderstandings - unknown until KOS. The most important one was ‘the guide vane that disappeared’. No quantitative estimation of the gains of this new awareness has been done but the team members felt really comfortable with the fact that this revealed now. Otherwise it could have turned out to be a major - very expensive - problem later in the project.

These preliminary results indicate that KOS is an efficient method to create redundancy and to eliminate misunderstandings, and hence prevent major changes late in a development project originating from earlier misunderstandings between fellow team members who think that they understand one another.

Even though the implementation of KOS was a success one should be aware of the context of the implementation. I have developed the method, I have implemented the method at the company where I am employed in a gas turbine team where I know some of the participants, and I have evaluated the results. Of course I am biased (as described in section 2.5) and the question whether the results would be the same in another context is easily answered; they would not. Judging from the answers from the participants, which I believe to be quite honest, I think KOS has a good potential to be useful in other applications as well. Still, more applications in different contexts are necessary to develop KOS further.
CHAPTER 7

CONCLUSIONS OF THE THESIS

In the last chapter I return to the research questions and draw the conclusions of the thesis. Also, further research and deployment of methods are discussed, before ending the thesis with some final words.

7.1 CONCLUSIONS

Based on my experience in Swedish industry and also on results from previous research found in the literature, I claim that people need to talk to one another to be able to understand one another.

This project aims at delivering methods that are intended to improve effectiveness of product development, i.e. fewer misunderstandings will contribute to improved quality and, as a consequence, lowered costs and shortened lead-times. The project also aims at delivering a method that is intended to improve organizational learning, which would in turn improve a company’s ability to adapt more easily to a changing environment. The ultimate goal and vision is more competitive companies.

Based on these experiences and assumptions two research questions have been stated. The conclusions of these two questions are given in the following sections.
7.1.1 Improved understanding

I return to the first research question of this thesis:

**RQ1:** How can understanding between engineers from different backgrounds in a product development organization be improved?

In this thesis I present three possible methods for improving communication between engineers. From the applications at ABB STAL I conclude that all three methods have been successful in improving understanding and reducing misunderstandings between engineers from different domains, each method in a specific way.

- ‘**Phantom Turbine Development**’ is a method for people engaged in technology and process development to share goals and visions based on future customer needs. This will ensure that everybody is heading in the same direction and will reduce rivalry and sub-optimization between departments.
- ‘**Process Improvement Simulations**’ are a method for simulating and comparing improvements to the development process before they actually take place. It is a method that engineers can use to understand and speed up iterations, not by working faster but by working smarter, without the need for more project management supervision and control.
- ‘**Knowledge Overlapping Seminars (KOS)**’ are a communication method for engineers in a product development team with the purpose of creating overlapping knowledge domains, and hence a common language that will reduce misunderstandings. Obstacles that occur in ‘ordinary meetings’ are avoided in a KOS.

7.1.2 Improved organizational learning

Continuing with the second research question of this thesis:

**RQ2:** How to improve organizational learning within a product development organization?

In chapter 3 a possible answer to the second research question is proposed. ‘**An Engineering Management Model for Improvement of Organizational Learning**’ is a theoretical model of how three management disciplines can be used together to improve organizational learning within a product development organization. Research question **RQ2** is re-phrased to **RQ2a** ‘Does the proposed engineering management model constitute a tool for improving organizational
learning within a product development organization?’. I conclude that it does. I base the conclusion on a) ‘organizational learning’ aims at establishing a ‘learning organization’, b) a ‘learning organization’ can be described by Senge’s five disciplines, c) the five disciplines can be identified in the Engineering Management Model, d) the model is defined by three - individually - well-known and successful management disciplines of engineering management and hence e) by combining and developing these management disciplines together we can facilitate improvement of organizational learning within a product development organization.

The model presented is a theoretical model. To apply the model practically in a product development organization practical methods for applying the three paths in the model are needed. In chapters 4, 5, and 6 one method for each path in the model is presented. In addition to improving understanding between engineers, these methods could, applied together and at different levels in the organization, be a practical solution to the second research question.

The model is a ‘tool’ in the sense that it can be used as a common abstract concept of how to improve organizational learning within engineering management. By using the model people from different domains and different levels in the organization can translate the abstract concept of organizational learning within engineering management to his/her own concrete concepts of organizational learning. This ensures a process where the personal concepts are in accordance with the organization’s i.e. others’ personal concrete concepts and the organization’s overall goal. By sharing the knowledge behind these concrete concepts and hence developing redundancy in the organization can hopefully give a shared mental model of organizational learning within product development. I.e. the abstract ‘tool’ can serve as a concrete ‘help’ when improving organizational learning within a product development organization.

7.2 FURTHER RESEARCH

The two recently designed methods, presented in this thesis, i.e. ‘Process Improvement Simulations’ and ‘Knowledge Overlapping Seminars’, need to be tested and developed further in industrial applications. Furthermore, the theoretical model ‘An Engineering Management Model for Improvement of Organizational Learning’ needs to be tested and developed in ‘practical’ applications. These developments could form a natural continuation of this research project, but any researcher within Engineering Management who finds the methods interesting is invited to develop them further.
7.3 Deployment of Methods

Don Clausing wrote in his evaluation of ENDREA (Clausing, 1998): “An effective deployment (technology transfer) plan is needed. Only a small start has been made. [...] Additional strong deployment activities will be needed to achieve the necessary cultural change in industry to capture the needed rate of growth in productivity.”

My contribution to this cultural change in industry will be to apply the methods presented in this thesis further at my company, now called ABB ALSTOM POWER. Several development projects have been identified as possible for running KOS in the teams. The projects are of different types, spanning from gas turbine development projects to business systems development projects. It is also my hope that I will continue to apply and further develop the Engineering Management Model to realize the benefits and potential gains of organizational learning within a product development organization.

If given the opportunity I will also develop ‘User’s Manuals’ for the methods presented, which would ease the deployment to other companies as well.

7.4 Final Words

As individuals we learn from mistakes, and change behaviour accordingly. If our organization were able to do that, the organization would have to behave like an individual. An individual ‘shares visions’ with himself, hence knows where he is going. An organization that does not share visions does not know where it is going. An individual ‘shares mental models’ with himself, hence knows what he is doing and why he is doing it. An organization that does not share mental models does not know what it is doing and why it is doing it. Both an individual and an organization will respond in accordance to how they are controlled. For instance, if the control demands that time schedules must be fulfilled, quality will not be given priority. That is why systems thinking is so important. Furthermore, in a changing environment both the individual and the organization have to be able to adapt their working methods, procedures, and priorities, thus motivating personal mastery and team learning. As we have seen, Senge’s five disciplines are the framework that a learning organization could be built around. If the proposed methods, presented in this thesis, could be used to realize an improved organizational learning within product development, this would be a successful industrially relevant project. I hope so.
Finally, some words from a very logical man. Even though he has never existed in real life, what he says is true in real life.

“It would be illogical to assume that all conditions remain stable.”

Mr. Spock in ‘Star Trek - The Enterprise Incident’, stardate 5027.3

“Change is the essential process of all existence.”

Mr. Spock in ‘Star Trek - Let That Be Your Last Battlefield’, stardate 5730.2


APPENDIX 1: MATLAB FILES

1. Matlab m files used for example of Process improvement simulations
ReadMe.txt:
-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-

An example of Process Improvement Simulations, using Matlab.

Save "An_example.m" and "calctpt.m" in a new directory, e.g. "C:\Matlab\work\An_example".

"calctpt.m" is a general function/m-file for calculating and plotting Total Process Time.

"An_example.m" is a special example of Process Improvement Simulations, including some sample data. The function "calctpt.m" is used several times in the example.

To run the example, do like this:
1. Start Matlab.
2. Go to the new directory.
3. Type "An_example" (notice that Matlab is case sensitive).

Notice. I take no responsibility whatsoever for the accuracy of the results from these files. Also, notice that the files are not in any way the responsibility of MathWorks.

It is all right to copy and use the files as long as you state the source.
1999 Peter Cronemyr ( come.to/cronemyr ; cronemyr@usa.net )

More information on Matlab: http://www.mathworks.com

-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-
calctpt.m:
-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-

function [tpt,U,WU]=calctpt(A,W,num_it,col)
% % CALCTPT Calculates the Total Process Time.
% [TPT,U,WU]=CALCTPT(A,W,NUM_IT,COL)
% Calculates the Total Process Time TPT by use of either
% eigenvectors and eigenvalues or iteration.
% NOTICE! The use of eigenvectors and eigenvalues may give
% inaccurate results, due to a close-to-singular or badly
% scaled eigenvector matrix (V).
% INPUT ARGUMENTS:
% #1: A (required)
% The transformation matrix containing re-work fractions.
% A sufficient, but not necessary, criterion for convergence
% is that the entries in either every row or in every column
% of the transformation matrix A sum to less than one.
% #2: W (required)
% The task time matrix (diagonal).
% #3:NUM_IT (optional)
% If NUM_IT is omitted eigenvectors and eigenvectors are used,
% otherwise an iterative solution is given with NUM_IT(>0)
% iterations (see the note above!).
% #4: COL (optional)
% If COL is omitted the line will be blue.
% OUTPUT ARGUMENTS:
% #1: TPT (required)
% Total Process Time either by eigenvalue solution or by
% iterative solution.
% #2: U (optional)
% The total work vector U after convergence or truncated
% iteration.
% #3: WU (optional)
% The total process time vector WU after convergence or
% truncated iteration.
% vvvvvvvvvvvvvv Do not delete the following lines please vvvvvvvvvvvvvv
% It is all right to copy and use this file as long as you state the source.
% 1999 Peter Cronemyr (come.to/cronemyr; cronemyr@usa.net)
%
%

FontSize=10;

% Make Initial Work Vector
size_of_matrix = max(size(A));
u0 = ones(size_of_matrix,1);

if nargin<3
% Use eigenvalues and eigenvectors

% Eigenvectors and eigenvalues of A
[V,D] = eig(A);

% Calculate Total Work Vector
I = eye(size_of_matrix);
U = V * ((I - D) \ (V \ u0));
WU = W * U;

% Calculate Total Process Time
tpt = real(sum(WU));

else
% Use iteration

U = u0;
WU = W * U;
tptv(1) = sum(WU);
iptv(1) = sum(WU);
tpt= sum(WU);
if num_it>1
    for i=1:num_it-1
        u1=A*u0;
        U=U+u1;
        WU = W * U;
        tptv(i+1) = sum(WU);
        iptv(i+1) = tptv(i+1) - tptv(i);
        tpt= tptv(i+1);
        u0=u1;
    end
end

% Plotting
if nargin<4, col='b'; end
h=plot(tptv,[col '-' ]);  
set(h,'LineWidth',5);
hold on
h=plot(iptv,[col '--']); 
set(h,'LineWidth',3);
set(gca,'FontSize',FontSize);
ax=axaxis;
axis([1 num_it 0 ax(4)]);
grid on
title('Total Process Time');
xlabel('Iteration');
ylabel('Time/iteration (dashed) and TPT (solid)');
end
An example.m:
-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-

% % AN EXAMPLE:
% % Simulation of two different process improvements
% and also a combination of the two.
% % Uses the general function/m-file calctpt.
% % Do not delete the following lines please
% % It is all right to copy and use this file as long as you state the source.
% 1999 Peter Cronemyr ( come.to/cronemyr ; cronemyr@usa.net )
% %
% FontSize=10;
% as is
% - task times
Wasis=[ 1.0 0 0 0 0 0
0 1.5 0 0 0 0
0 0 0.3 0 0 0
0 0 0 0.8 0 0
0 0 0 0 1.6 0
0 0 0 0 0 0.9];

% - re-work fractions
Aasis=[ 0.0 0 0 0 0 0
0.5 0.0 0 0 0.5 0
0 0.4 0.0 0 0 0
0 0.3 0.0 0 0 0
0 0.1 0.3 0.5 0 0.4
0 0 0 0 0 0.2 0.0];

figure
[tptasis,Uasis,WUasis]=calctpt(Aasis,Wasis,10,'b');

% to be 1
% - new re-work fractions
A1=[ 0.0 0 0 0 0 0
0.5 0.0 0 0 0.25 0
0 0.4 0.0 0 0 0
0 0.3 0.0 0 0 0
0 0.05 0.15 0.25 0.0 0.2]
0 0 0 0 0.1 000];

[tpttobe1,Utobe1,WUtobe1]=calctpt(A1,Wasis,10,'g');
set(gca,'FontSize',FontSize);
h=title(['Work smarter: STAR1=' num2str(tpttobe1/tptasis)]);
set(h,'FontSize',10);

% as is
figure;
[tptasis,Uasis,WUasis]=calctpt(Aasis,Wasis,10,'b');

% to be 2
% - new task times
W2=[1.0 0 0 0 0 0
    0 1.5 0 0 0 0
    0 0 0.3 0 0 0
    0 0 0 0.8 0 0
    0 0 0 0 0.8 0
    0 0 0 0 0 0.9];

[tpttobe2,Utobe2,WUtobe2]=calctpt(Aasis,W2,10,'g');
set(gca,'FontSize',FontSize);
h=title(['Work faster: STAR2=' num2str(tpttobe2/tptasis)]);
set(h,'FontSize',FontSize);

% as is
figure;
[tptasis,Uasis,WUasis]=calctpt(Aasis,Wasis,10,'b');

% to be 3 = 1 + 2
% - new re-work fractions and new task times

[tpttobe3,Utobe3,WUtobe3]=calctpt(A1,W2,10,'g');
set(gca,'FontSize',FontSize);
h=title(['Work smarter and faster: STAR3=' num2str(tpttobe3/tptasis)]);
set(h,'FontSize',FontSize);

% plot U as is and to be 1
figure;
bar(Uasis,'b')
hold
ax=axis;
axis([0 max(size(Uasis))+1 0 ax(4)])
offset=0.3;
bar((1+offset:max(size(Utobe1))+offset),Utobe1,'g')
set(gca,'FontSize',FontSize);
title('U1');
xlabel('Activity');
ylabel('Work');

% plot WU as is and to be 1

figure
bar(WUasis,'b')
hold
ax=ax;
axis([0 max(size(WUasis))+1 0 ax(4)])
offset=0.3;
bar((1+offset:max(size(WUotbel))+offset),WUotbel,'g')
set(gca,'FontSize',FontSize);
title('WU1');
xlabel('Activity');
ylabel('Time');

% plot U as is and to be 2

figure
bar(Uasis,'b')
hold
ax=ax;
axis([0 max(size(Uasis))+1 0 ax(4)])
offset=0.3;
bar((1+offset:max(size(Utobe2))+offset),Utobe2,'g')
set(gca,'FontSize',FontSize);
title('U2');
xlabel('Activity');
ylabel('Work');

% plot WU as is and to be 2

figure
bar(WUasis,'b')
hold
ax=ax;
axis([0 max(size(WUasis))+1 0 ax(4)])
offset=0.3;
bar((1+offset:max(size(WUotbe2))+offset),WUotbe2,'g')
set(gca,'FontSize',FontSize);
title('WU2');
xlabel('Activity');
ylabel('Time');

% plot U as is and to be 3

figure
bar(Uasis,'b')
hold
ax=axis;
axis([0 max(size(Uasis))+1 0 ax(4)])
offset=0.3;
bar([1+offset:max(size(Utobe3))+offset],Utobe3,'g')
set(gca,'FontSize',FontSize);
title('U3');
xlabel('Activity');
ylabel('Work');

%plot WU as is and to be 3

figure
bar(WUasis,'b')
hold
ax=axis;
axis([0 max(size(WUasis))+1 0 ax(4)])
offset=0.3;
bar([1+offset:max(size(WUtobe3))+offset],WUtobe3,'g')
set(gca,'FontSize',FontSize);
title('WU3');
xlabel('Activity');
ylabel('Time');

-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-x-
APPENDIX 2: PRESENTATION SLIDES

2. Presentation slides about KOS used at ABB STAL (translated from Swedish)
Knowledge Overlapping Seminars

= KOS

What’s that?

A research project within ENDREA.
Peter Cronemyr, industrial doctoral student ABB STAL.

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ABB STAL
Linköpings Universitet
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1999 Peter Cronemyr
Knowledge overlapping gives a common language

a condition for fewer misunderstandings and a better understanding of the whole
“We talk to each other every day. Why do we need a knowledge overlapping seminar?”

We talk about concrete concepts but we have superficial knowledge about neighboring domains.

We coordinate the concrete concepts in project meetings and with common IT tools but we do not know what lies behind the superficial knowledge.

We need a method to communicate ‘deep’ profound knowledge and let our tacit knowledge up to the surface.
Different ways to increase integration and communication within product development:

Holistic Product Development: See the whole
Goal sharing and a common view of the product development process.

Project Management: Speed
Coordination of tasks and streamlining of information flows.

Knowledge Management: Common language
Methods to develop and share knowledge.
In a knowledge overlapping seminar an engineer shares his domain-specific knowledge
How is a KOS carried out

Steps in the implementation of a KOS:

1. The project team settles on the common task right now, something that everybody knows, e.g. to design a blade, a combustor or a control system.

2. Identify two or at most three domains/engineering disciplines that form parts of the team, e.g. aerodynamics, mechanical integrity and mechanical design.

3. Choose a teacher from each domain.

4. The teachers prepare their presentations, see the page: Preparations by the teacher.

5. All participants fill out a questionnaire before each seminar.

6. Carry out KOS, see page:
   Rules that apply for the knowledge overlapping seminar:
   Two domains give two KOS, three domains give six KOS, four give twelve....

7. All participants fill out a questionnaire after each seminar.

8. Evaluation of questionnaires to measure the results, improve the process and plan for a continuation.
Preparations by the teacher

The teacher does not need to be the person with the most specialized knowledge within the domain. It is more important that he/she has the right qualities:

- be a good educationalist
- finds it easy to talk and to listen
- understands that everybody does not understand “self-evident facts.”

The teacher prepares his/her KOS alone or possibly together with a neutral seminar facilitator (not a member of any of the chosen domains). Steps in the preparatory work:

1. The teacher starts by describing one specific concrete task that his/her domain is responsible for as a part of the common abstract task. This is superficial knowledge, i.e. answers on ‘what’ and ‘how’ that most engineers in the team already know about. There is no need to describe this thoroughly. Estimate that this point will need approximately ten minutes presentation at the KOS.

2. Then the teacher asks himself/herself “Why is this important?”. The questions that are most difficult to answer often address tacit knowledge.

3. The teacher continues to ask ‘why’ five times until he/she has reached down to profound knowledge. This knowledge can be e.g. classical physics or something else that engineers from different domains share from a common education. The way down to profound knowledge is domain-specific knowledge that engineers outside the domain have no access to.
Rules that apply for the knowledge overlapping seminar (KOS)

The teacher is from one domain (A) and the pupils from another domain (B). It is very important that no more engineers from the teacher’s domain (A) participate in the seminar to avoid:

- Unnecessarily detailed discussions between the teacher and the other ‘A engineer’ which would lead to the ‘B engineers’ starting to think about something else and would prevent them from asking ‘silly’ questions with the risk of losing prestige.
- The teacher would become nervous because he/she is trying to express things that maybe an ‘expert’ from A may have other opinions about.

If there are more than two domains (A, B, C) then the teacher has to have several KOS. It is important that all pupils come from the same domain and share the language.

What is new with KOS?

- In traditional education knowledge is derived from fundamental knowledge ‘upwards’ to more specialized knowledge but it is seldom connected to a common task. It is difficult to see the connection between the new knowledge and the current specific task.
- A KOS starts with a common abstract task and via a concrete task the problem is derived ‘backwards’ down to common profound knowledge. It is easier to see the connection between the new knowledge and the current specific task.
When should KOS be arranged?

When?

When a project is started the team usually develops a project specification with goals, schedule and milestones. Then it is appropriate to reserve a half day for each KOS. E.g. Three domains give six KOS which would take two to three days. These days will lead to a reduction of the amount of rework later in the project.

How often?

For long projects and for continuous work in the functional organization it is sufficient to arrange KOS approximately once per year (or more often).

How?

To achieve successful integration of domains all three paths in the ♦ model have to be used:

• Holistic Product Development:  *See the whole*,
• Project Management:  *Speed*,
• Knowledge Management:  *Common language*.
APPENDICES 3 & 4: QUESTIONNAIRES

3. Questionnaire used before KOS at ABB STAL
   (translated from Swedish)

4. Questionnaire used after KOS at ABB STAL
   (translated from Swedish)
Questionnaire before a Knowledge Overlapping Seminar 3:1

Questionnaire:  
Read the glossary (last page) before answering the questions

I. Your name: __________________________________________________________
   If you prefer to be anonymous it is all right to make up a name and then stick to that. It is needed to be able to compare the answers before and after KOS. Remember your name!

II. Today’s date: _________________________________________________________
III. The date for KOS (if not today): _________________________________________
IV. The name of your domain: ______________________________________________
V. The name of the other domain: ___________________________________________
VI. Are you a pupil ☐ or a teacher ☐ in this KOS?

Choose one answer in questions 1-4 below.

1. What do you think about your own knowledge about the other domain?
   ( ) I do not know anything about the other domain.
   ( ) I have some superficial knowledge about the other domain.
   ( ) I have some profound knowledge about the other domain.
   ( ) I have quite a lot profound knowledge about the other domain.
   ( ) I have extensive profound knowledge about the other domain.
   ( ) I do not know.
   ( ) I decline to answer.

2. What knowledge about the other domain do you think you need?
   ( ) I do not need to know anything about the other domain.
   ( ) I need some superficial knowledge about the other domain.
   ( ) I need some profound knowledge about the other domain.
   ( ) I need quite a lot profound knowledge about the other domain.
   ( ) I need extensive profound knowledge about the other domain.
   ( ) I do not know.
   ( ) I decline to answer.

3. What do you think about the knowledge that the people in the other domain have about your domain?
   ( ) Most of them do not know anything about my domain.
   ( ) Most of them have some superficial knowledge about my domain.
   ( ) Most of them have some profound knowledge about my domain.
   ( ) Most of them have quite a lot profound knowledge about my domain.
   ( ) Most of them have extensive profound knowledge about my domain.
   ( ) I do not know.
   ( ) I decline to answer.

4. What knowledge about your domain do you think the people in the other domain need?
   ( ) Most of them do not need to know anything about my domain.
   ( ) Most of them need some superficial knowledge about my domain.
   ( ) Most of them need some profound knowledge about my domain.
   ( ) Most of them need quite a lot profound knowledge about my domain.
   ( ) Most of them need extensive profound knowledge about my domain.
   ( ) I do not know.
   ( ) I decline to answer.

1999 Peter Cronemyr
**Glossary - definitions of words used in KOS:**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information</td>
<td>Some type of data or observation. Information can be stored in databases.</td>
</tr>
<tr>
<td>Communication</td>
<td>Exchange of information, e.g. through conversation or with Information Technology.</td>
</tr>
<tr>
<td>Knowledge</td>
<td>Knowledge is created when information is viewed in a context (with relations and holism) by relating the new information to a theory or previous knowledge which makes it possible to make predictions. Knowledge resides in people’s brains, not in databases.</td>
</tr>
<tr>
<td>Superficial knowledge</td>
<td>To recognize words that are used within a domain. Often the answer to “what?”.</td>
</tr>
<tr>
<td>Profound knowledge</td>
<td>To have an intellectual depth and insight into words that are used within a domain and how these are connected. Often the answers to “how?” and “why?”.</td>
</tr>
<tr>
<td>Tacit knowledge</td>
<td>The knowledge that can not be expressed in words. Not even to oneself.</td>
</tr>
<tr>
<td>Competence</td>
<td>The ability to use one’s knowledge.</td>
</tr>
<tr>
<td>Learning</td>
<td>To increase one’s knowledge or competence by reflection of one’s own habits, thoughts, and beliefs.</td>
</tr>
<tr>
<td>Experience</td>
<td>Increased understanding through recurring opportunities for learning. Experience is often tacit knowledge.</td>
</tr>
<tr>
<td>Domain</td>
<td>A group of people with a common language built on common profound and tacit knowledge. It may be an engineering discipline, a group of people with a common education, or people with a common interest.</td>
</tr>
<tr>
<td>One’s own domain</td>
<td>Often one’s own department since departments usually are divided according to functional disciplines.</td>
</tr>
<tr>
<td>Other domains</td>
<td>Those departments/groups/disciplines which I cooperate with but which have their own languages, built on their own knowledge.</td>
</tr>
<tr>
<td>Knowledge overlapping</td>
<td>To move the borders of domains towards each other so the domains overlap by teaching each other over the domain borders instead of moving the borders away from each other which is a result of specialization.</td>
</tr>
<tr>
<td>KOS</td>
<td>Knowledge Overlapping Seminar (English abbreviation). A structured way to achieve knowledge overlapping.</td>
</tr>
<tr>
<td>Teacher in a KOS to</td>
<td>The person who will try to transfer profound knowledge about a domain people of another domain.</td>
</tr>
<tr>
<td>Pupils in a KOS</td>
<td>The people who are listening and asking questions to a teacher to get knowledge about another domain.</td>
</tr>
</tbody>
</table>
Questionnaire after a Knowledge Overlapping Seminar 4:1

Questionnaire: Read the glossary before answering the questions

I. Your name: __________________________________________________________
   Remember to use the same name as you did before KOS!

II. Today’s date: _________________________________________________________

III. The date for KOS (if not today): _________________________________________

IV. The name of your domain: ______________________________________________

V. The name of the other domain: ___________________________________________

VI. Are you a pupil □ or a teacher □ in this KOS?

Choose one answer in questions 1-5 below.

1. What do you think about your own knowledge about the other domain?
   ( ) I do not know anything about the other domain.
   ( ) I have some superficial knowledge about the other domain.
   ( ) I have some profound knowledge about the other domain.
   ( ) I have quite a lot profound knowledge about the other domain.
   ( ) I have extensive profound knowledge about the other domain.
   ( ) I do not know.
   ( ) I decline to answer.

2. What knowledge about the other domain do you think you need?
   ( ) I do not need to know anything about the other domain.
   ( ) I need some superficial knowledge about the other domain.
   ( ) I need some profound knowledge about the other domain.
   ( ) I need quite a lot profound knowledge about the other domain.
   ( ) I need extensive profound knowledge about the other domain.
   ( ) I do not know.
   ( ) I decline to answer.

3. What do you think about the knowledge that the people in the other domain have about your domain?
   ( ) Most of them do not know anything about my domain.
   ( ) Most of them have some superficial knowledge about my domain.
   ( ) Most of them have some profound knowledge about my domain.
   ( ) Most of them have quite a lot profound knowledge about my domain.
   ( ) Most of them have extensive profound knowledge about my domain.
   ( ) I do not know.
   ( ) I decline to answer.

4. What knowledge about your domain do you think the people in the other domain need?
   ( ) Most of them do not need to know anything about my domain.
   ( ) Most of them need some superficial knowledge about my domain.
   ( ) Most of them need some profound knowledge about my domain.
   ( ) Most of them need quite a lot profound knowledge about my domain.
   ( ) Most of them need extensive profound knowledge about my domain.
   ( ) I do not know.
   ( ) I decline to answer.
5. How do you view the use and benefit that you will have from the knowledge gained at this KOS?
   ( ) No use and benefit whatsoever.
   ( ) I will maybe have some use and benefit from the knowledge I have gained.
   ( ) I will probably have some use and benefit from the knowledge I have gained.
   ( ) I will surely have some use and benefit from the knowledge I have gained.
   ( ) I will surely have much use and benefit from the knowledge I have gained.
   ( ) I do not know.
   ( ) I decline to answer.

Choose one or several answers in question 6 below.

6. Has your knowledge about the other domain changed due to this KOS?
   ( ) No.
   ( ) Yes, my knowledge about the other domain has increased.
   ( ) Yes, my knowledge about the other domain has decreased.
   ( ) Yes, my knowledge about the other domain has become more profound.
   ( ) Yes, my knowledge about the other domain has become more superficial.
   ( ) Yes, my knowledge about the other domain has changed in the following way:

   .................................................................
   .................................................................
   .................................................................
   .................................................................
   .................................................................
   .................................................................
   .................................................................

   ( ) I do not know.
   ( ) I decline to answer.

7. Do you have any suggestions of improvements of the design or content of this KOS, including this questionnaire?

   .................................................................
   .................................................................
   .................................................................
   .................................................................
   .................................................................
   .................................................................
   .................................................................
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   .................................................................

1999 Peter Cronemyr
APPENDIX 5: ANALYSIS

5. Analysis of questionnaires and semi-structured interviews after all six KOS at ABB STAL (translated from Swedish)
Analysis of Knowledge Overlapping Seminars

KOS in Project GT35C Marine. Analysis of Questionnaires and Semi-Structured Interviews.

Number of KOS. Six (6), Totally 150 man-hours, October 8th through 26th, 1999.

Location. ABB STAL HQ, Finspång Manor House.

Common task of the project. “To re-design the GT35C compressor turbine for marine application”

Domains. Mechanical design (4 people), Mechanical integrity (4 people) and Aerodynamic design (4 people). All participants were pupils. One person from each domain was also teacher (two KOS per teacher).

Seminar leader. Peter Cronemyr.

Analysis of Questionnaires:
Opinions about Own Knowledge

<table>
<thead>
<tr>
<th>Question to be analyzed</th>
<th>Results</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. How much knowledge about the teacher’s domain (A) do the pupils from domain (B) possess? (answers from pupils)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A knowledge within B. before KOS:</td>
<td></td>
<td>Before KOS three of four (73%) think they have some superficial knowledge about the teacher’s domain. One of four (23%) think they have more profound knowledge.</td>
</tr>
<tr>
<td>A knowledge within B. after KOS:</td>
<td></td>
<td>After KOS more than one of two (64%) think they have some profound knowledge about the teacher’s domain. The remaining (36%) have some superficial knowledge.</td>
</tr>
</tbody>
</table>
### Question to be analyzed

<table>
<thead>
<tr>
<th>ii. Has the knowledge about the teacher’s domain (A) changed due to KOS? (answers from pupils, before and after KOS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>iii. How much knowledge about the teacher’s domain (A) do the pupils from domain B need? (answers from pupils)</td>
</tr>
</tbody>
</table>

### Results

#### Knowledge after KOS

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>No. of answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>nothing</td>
<td>1</td>
</tr>
<tr>
<td>some superficial</td>
<td>7</td>
</tr>
<tr>
<td>some profound</td>
<td>9</td>
</tr>
<tr>
<td>quite a lot</td>
<td>4</td>
</tr>
<tr>
<td>extensive</td>
<td>1</td>
</tr>
<tr>
<td>do not know</td>
<td>1</td>
</tr>
<tr>
<td>decline t. a.</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Need for A knowledge within B, before KOS:

<table>
<thead>
<tr>
<th>Need for A knowledge</th>
<th>No. of answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>nothing</td>
<td>0</td>
</tr>
<tr>
<td>some superficial</td>
<td>1</td>
</tr>
<tr>
<td>some profound</td>
<td>14</td>
</tr>
<tr>
<td>quite a lot profound</td>
<td>7</td>
</tr>
<tr>
<td>extensive</td>
<td>0</td>
</tr>
<tr>
<td>do not know</td>
<td>0</td>
</tr>
<tr>
<td>decline t. a.</td>
<td>0</td>
</tr>
</tbody>
</table>

#### Need for A knowledge within B, after KOS:

<table>
<thead>
<tr>
<th>Need for A knowledge</th>
<th>No. of answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>nothing</td>
<td>0</td>
</tr>
<tr>
<td>some superficial</td>
<td>1</td>
</tr>
<tr>
<td>some profound</td>
<td>11</td>
</tr>
<tr>
<td>quite a lot profound</td>
<td>10</td>
</tr>
<tr>
<td>extensive</td>
<td>0</td>
</tr>
<tr>
<td>do not know</td>
<td>0</td>
</tr>
<tr>
<td>decline t. a.</td>
<td>0</td>
</tr>
</tbody>
</table>

### Analysis

Almost one of two (45%) have more profound knowledge after KOS than before KOS. One person (5%) has got more superficial knowledge.

*See also {viii.} below.*

Most pupils (95%) think they need profound knowledge about the teacher’s domain.

Before KOS one third (32%) think that they need quite a lot of profound knowledge.

After KOS the fraction that think they need quite a lot of profound knowledge has increased to almost one of two (45%).
### iv. Have the opinions about the need for knowledge about the teacher’s domain (A) changed due to KOS? (answers from pupils, before and after KOS)

#### Need for knowledge after KOS

<table>
<thead>
<tr>
<th>No. of answers</th>
<th>nothing</th>
<th>some superf.</th>
<th>some prof.</th>
<th>q. a l. prof.</th>
<th>ext. prof.</th>
<th>do not know</th>
<th>decline t. a.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>before KOS</td>
<td>1</td>
<td>9</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>after KOS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

One fourth (23%) need more profound knowledge after KOS than before KOS. For two pupils (9%) the need for profound knowledge has decreased during KOS.

### v. How do the A knowledge and the need for A knowledge within the pupils’ domain (B) relate? (answers from pupils)

#### Before KOS:

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>nothing</th>
<th>some superf.</th>
<th>some prof.</th>
<th>q. a l. prof.</th>
<th>ext. prof.</th>
<th>do not know</th>
<th>decline t. a.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of answers</td>
<td>12</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Before KOS most pupils (86%) think that they have too superficial knowledge about the teacher’s domain. No one thinks that they have too profound knowledge.

#### After KOS:

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>nothing</th>
<th>some superf.</th>
<th>some prof.</th>
<th>q. a l. prof.</th>
<th>ext. prof.</th>
<th>do not know</th>
<th>decline t. a.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of answers</td>
<td>12</td>
<td>6</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

After KOS two of three (68%) think that they have too superficial knowledge about the teacher’s domain. One person (5%) thinks that he has too profound knowledge.
## ANALYSIS OF QUESTIONNAIRES:
### OPINIONS ABOUT OTHERS’ KNOWLEDGE

<table>
<thead>
<tr>
<th>Question to be analyzed</th>
<th>Results</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>vi. Have the opinions about B knowledge within the teacher’s domain (A) changed due KOS?</td>
<td>Others’ knowledge after KOS</td>
<td>Most pupils (95%) have not changed opinions about the B knowledge within the teacher’s domain (A). One person (5%) has changed opinion to ‘they know nothing about my domain’.</td>
</tr>
<tr>
<td></td>
<td>No. of answers</td>
<td>nothing</td>
</tr>
<tr>
<td></td>
<td>others’ knowledge before KOS</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>others’ knowledge before KOS</td>
<td>2</td>
</tr>
</tbody>
</table>
| vii. Have the opinions about the need for B knowledge within the teacher’s domain (A) changed due KOS? | Others’ need for knowledge after KOS | Four of five (82%) have not changed opinions about the need for B knowledge within the teacher’s domain (A). One of five (18%) have changed opinions to ‘they need more profound knowledge’.
| | No. of answers | nothing | some superficial | some profound | quite a lot superficial | quite a lot profound | quite a lot extensive | do not know | decline t. a. |
| | others’ need for knowledge before KOS | 2 | 1 | 11 | 3 | 5 | | | |
| | others’ need for knowledge before KOS | 2 | 1 | 11 | 3 | 5 | | | |
ANALYSIS OF QUESTIONNAIRES:
OPINIONS ABOUT THE EFFECTS OF THE SEMINAR

viii. How do the participants experience that the knowledge about the other domain has changed due to KOS? (Answers from pupils and teachers, directly after KOS and one month after KOS)

<table>
<thead>
<tr>
<th>Question to be analyzed</th>
<th>Results</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directly after KOS:</td>
<td></td>
<td>Directly after KOS: Most participants (86%) have increased and/or got more profound knowledge due to KOS. More participants think that their knowledge has increased (69%) than those that think that they have got more profound knowledge (38%). No one thinks that their knowledge has decreased or got more superficial.</td>
</tr>
<tr>
<td>Change of knowledge depth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of answers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>increased</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>no change</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>decreased</td>
<td></td>
<td></td>
</tr>
<tr>
<td>do not know</td>
<td></td>
<td></td>
</tr>
<tr>
<td>decline t. a.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Change of knowledge quantity |         |         |
| No. of answers               |         |         |
| increased                    | 3       | 8        | 3       |
| no change                    | 5       | 2        | 1        |
| decreased                    |          |          |          |
| do not know                  |          |          |          |
| decline t. a.                |          |          | 7        |

One month after KOS: Most (86%) of those who filled out the questionnaire one month after KOS (response frequency 76%) think that their knowledge has increased or has got more profound. More than one of two (64%) think that their knowledge has increased. One third (36%) think that the knowledge has become more profound while one of seven (14%) think it has become more superficial (with the comment “I thought I had profound knowledge. Now I know that it was superficial”). One person answered more profound and more superficial (presented as ‘do not know’).

See also {ii.} above.
### Question to be analyzed

ix. How do the participants view the use and benefit that they will have from the knowledge gained at this KOS? *(Answers from pupils and teachers, directly after KOS and one month after KOS)*

### Results

**Usage: One month after KOS**

<table>
<thead>
<tr>
<th>No. of answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>no use</td>
</tr>
<tr>
<td>maybe some</td>
</tr>
<tr>
<td>probably some</td>
</tr>
<tr>
<td>surely some</td>
</tr>
<tr>
<td>surely much</td>
</tr>
<tr>
<td>do not know</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>do not know</th>
<th>decline t. a.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### Analysis

Directly after KOS:
Everybody (100%) thinks that they will have some use and benefit from the knowledge gained at this KOS.

Almost half of those (45%) are sure that they will have use and benefit from the new knowledge.

One month after KOS:
Everybody (100%) of those that filled out the questionnaire one month after KOS (response frequency 76%) thinks that they will have some use and benefit from the knowledge gained at this KOS.

More than half of those (64%) are sure that they will have use and benefit from the new knowledge.

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1999 Peter Cronemyr
**ANALYSIS OF SEMI-STRUCTURED INTERVIEWS**

Semi-structured interviews. Five questions on a paper were shown to the interviewee, who then could speak freely on these questions for 30 minutes. I put it down the answers in writing under the corresponding question.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers (translated from Swedish)</th>
<th>Analysis</th>
</tr>
</thead>
</table>
| 1. What has been positive with KOS?          | • Formulation of the common task of the team. Gives an anchoring deep down in the project.  
• Good to formulate what we have achieved in the project, i.e the common task.  
• Suddenly we became a group.  
• A good way to introduce new team members in the project work.  
• There have been so many people involved in the project but now we all got the same information.  
• The possibility to ask questions directly about anything. In ordinary meetings you do not know what the others are talking about. You do not have time and do not dare to ask in ordinary meetings.  
• Easier to ask questions.  
• You could ask about things that you normally do not ask.  
• You could ask questions about things that you really wonder about. Otherwise you do not ask questions. In ordinary project meetings you do not go deep down.  
• Good to talk to one another.  
• I have learned that it is worthwhile to ask questions.  
• We are making so many mistakes due to lack of communication. KOS gives a two-way communication with time for reflection, unlike traditional project meetings where only the ‘short cut’ in the diamond model is used.  
• Positive to have prepared KOS as a teacher. Everybody should do it.  
• Useful to formulate (to oneself) one’s own domain knowledge. Reduces the ‘home blindness’.  
• Everybody needs to think about his own profound knowledge - not just the teachers. | Integration within the team. The formulation of the common task improved the integration within the team. It was further improved by the six seminars.  
The possibility to ask questions. In ordinary meetings the team members do not ask questions because: 1) There is no time, 2) One does not want to ask ‘silly’ questions, and 3) One does not know what to ask. In KOS these obstacles were not present.  
Formulating one’s own domain knowledge. Everybody should formulate and express their own domain knowledge, not only teachers. |
## Analysis of Knowledge Overlapping Seminars

<table>
<thead>
<tr>
<th>Question</th>
<th>Answers (translated from Swedish)</th>
<th>Analysis</th>
</tr>
</thead>
</table>
| 1. What has been positive with KOS?, *cont’d* | • The number of participants was good. Maybe up to 10 would have been OK. 20-30 would not have been good. In that case only some participants would have asked questions and would have talked to one another.  
• Good number of participants. Good form of seminar.  
• The number should be 5-6, maximum 10, so that the number of KOS could be less.  
• Not too many (max 10). Otherwise the interests and pre-knowledge vary too much.  
• All participants have had positive attitudes.  
• Interested pupils with many questions makes it fun and simple to teach. | *Number of participants.* Most participants think the number of participants in a KOS should be around five or six, and not more than ten, if everybody should be able to ask questions and take part in the dialogue.  
*Nice atmosphere.* The participants did not find KOS boring or tedious |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers (translated from Swedish)</th>
<th>Analysis</th>
</tr>
</thead>
</table>
| 1. What has been positive with KOS?, cont’d | • Big exchange ratio. The right way to learn between disciplines.  
• I have gained a deeper understanding. You do not get in contact with profound knowledge in ordinary work.  
• Understanding of the whole.  
• Misunderstandings became evident.  
• A new consciousness about the connections between disciplines.  
• Good with definitions of common concepts and expressions.  
• Got new awareness of certain concepts and why some activities are carried out.  
• Both new knowledge from KOS and a new awareness of who is dependent of my ‘small changes’.  
• I have gained a deeper awareness/knowledge about Aerodynamics. Understand more about the uncertainties in our input data. Makes me a better gas turbine engineer.  
• Understand why they do what they do. I can take them into consideration from the beginning of my work.  
• Good to know what is important.  
• Good with concrete tasks.  
• New knowledge and new awareness. Small changes to an old turbine can lead to serious consequences.  
• I have learned new things and have increased my interest for the other domains.  
• I have become aware of who has the knowledge I need.  
• Now I know what others do and how that constrains my work.  
• Good to go into details and to get to know what lies behind, what tools that are used, what manual work that has to be done, and what theories that lie behind.  
• You become aware of how things inter-connect. | Two types of new knowledge. 1) Definitions of concepts and keywords have given the participants new knowledge. 2) A new awareness has led to a new holistic view. Most participants think both these types have been valuable. |
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers (translated from Swedish)</th>
<th>Analysis</th>
</tr>
</thead>
</table>
| 2. What has been negative with KOS? | • The Mechanical Design KOS was not deep enough. It dealt more with design solutions instead of concept explanations.  
  • The Mechanical Design KOS was too superficial. Did not follow the diamond model. What does Mechanical Design do and why?  
  • The Aerodynamic Design KOS was too detailed. The Mechanical Design KOS was at a good comprehensive level, considering that it was the first seminar. | Different needs for profound knowledge. Most - but not all - participants think the knowledge of some KOS could have been deeper. |
|                                      | • Lack of time.  
  • Lack of time for preparations.  
  • Lack of time. Real life problems have higher priorities than KOS.  
  • I did not have time to prepare carefully enough (teacher). | Lack of time due to low priority. Most participants found it difficult to attend KOS because other activities had higher priority. |
|                                      | • Person dependent: background and personality are important (teacher).  
  • Some of the participants in KOS have not participated that much in the project work. It is harder to ask questions to people that you do not know.  
  • KOS could be arranged in projects or in functional departments. What is important is that all participating have a common task and that everybody knows each other. | Person dependent. It is important that the team members know one another socially. Some thought that they did not. |
|                                      | • It is important to have KOS in your native language. | Language. Two KOS were held in English instead of Swedish. One person thought it prevented him from asking questions. |
|                                      | • Stick to the time schedule. Generally poor conformance to rules of meetings at ABB STAL. | Conformance to rules of meeting. Generally poor conformance to rules of meetings also at KOS. |
### Question

How could KOS be improved?

### Answers (translated from Swedish)

- The teacher should hand out copies of the presentation slides. These could be complemented with own notes.
- The presentation slides should be clean and simple.
- Everybody should take their own notes.
- Many want some documentation from KOS, but realize that it can be hard to produce since much of the seminar is an unstructured dialogue. At least copies of the prepared slides could be handed out.
- It is important that the teacher prepares himself carefully.
- It is important to have a prepared and structured teacher who talks about profound knowledge, not just superficial concepts and concrete tasks.
- The teacher has to understand the design of the seminar and he also needs to be controlled during preparations. The preparations have to take some time.
- Start at a superficial level and then get more detailed.
- Start at a reasonable level and then go deeper at every KOS.
- The KOS should have continued for one more hour. Then we would have reached even further.
- Premises closer to work. Makes it possible to fetch things that are needed.

### Analysis

- **Documentation.** Many want some documentation from KOS, but realize that it can be hard to produce since much of the seminar is an unstructured dialogue. At least copies of the prepared slides could be handed out.
- **Preparations by the teacher.** The teacher should stick to the ‘diamond’ and talk more about profound knowledge and less about superficial knowledge.
- **The time for a KOS.** One person wanted KOS to be longer. The rest thought three hours including two short pauses was OK.
- **Premises for a KOS.** One person wanted to be nearer to the workplace. The rest did not mention that. The reason for using the Finspång Manor House was that it was well separated from the daily work with colleagues knocking on the door and telephones ringing.
<table>
<thead>
<tr>
<th>Question</th>
<th>Answers</th>
<th>Analysis</th>
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<tbody>
<tr>
<td>4. Do you have any suggestions how you should continue within the GT35C Marine project?</td>
<td>• Earlier in the project. • Another KOS in some months: “What was good/bad? and why?” • Another KOS: What mistakes have we made? What were the consequences? • Another KOS in half a year with new concrete tasks. • KOS should have been arranged earlier in the project. • New KOS that start at previous misunderstandings, e.g. “the guide vane that disappeared”.</td>
<td>Suggestions for continuation of KOS within the project: 1) KOS should have been arranged earlier, 2) KOS should be arranged again in six months, and 3) Next KOS may start from a previous misunderstanding.</td>
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<td></td>
<td>• KOS should be arranged at the beginning of a project. It will reduce the costs for ABB STAL since the misunderstandings will be reduced. • KOS should be arranged in every project, in the beginning and half way. • In long projects KOS should be arranged once every half year. • It should be natural to arrange KOS in every project, every now and then. First KOS one month after project start and new KOS around the common task after some (3-6) months. • Every project should start with KOS. • Some type of strategy: KOS in different project phases. Has to be agreed with the project management. • It is important that someone arranges KOS continuously, e.g. the project manager. • Project managers have to learn how to arrange KOS in their projects. • Project managers have to plan for KOS. They have to realize that it is needed in “my project”.</td>
<td>KOS in other projects. KOS should be a natural part in ordinary project management. All project managers should learn how to arrange KOS.</td>
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### Question 4. Do you have any suggestions how you should continue within the GT35C Marine project?, cont’d

<table>
<thead>
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<th>Answers (translated from Swedish)</th>
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<tbody>
<tr>
<td>• After participating in a KOS one should try to use the method in ordinary meetings, e.g. “two-people KOS”: first 5 minutes explanations, then ordinary meeting.</td>
<td>Change of behaviour. Some suggest new ways of working and communicating within the team and in bilateral meetings, inspired by KOS.</td>
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<tr>
<td>• KOS could be arranged as a part of preparations before meeting customers.</td>
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<td>• The way we work will change automatically after this, with more questions and more contacts.</td>
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<tr>
<td>• 4+4+4 of 20+20+20 [within Aero/Mech/MIT] have attended KOS. The rest should also attend.</td>
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<tr>
<td>• Everybody within the R&amp;D department (10 at a time) should listen to a teacher at a time. Seven domains lead to 7x6x10x3=1260 man-hours.</td>
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<tr>
<td>• More KOS, e.g. with the Service department.</td>
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<tr>
<td>• More KOS.</td>
<td></td>
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<tr>
<td>• Some more information on the borders between Mechanical Design &lt; &gt; Manufacturing.</td>
<td></td>
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<tr>
<td>• More KOS with narrower domains.</td>
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<tr>
<td>• Possible KOS: Materials &lt; &gt; MIT or CFD &lt; &gt; Blade Dynamics (both between functional departments)</td>
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### Question 5. Anything else that you want to put forward?

<table>
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<tbody>
<tr>
<td>• Society and companies are heading the wrong way with more and more specialization. KOS is a major change. It is important for the survival of the company</td>
<td>KOS for profit. Some think that KOS is a good way to increase the profit of the company.</td>
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<tr>
<td>• A new awareness that is very important for the company to utilize.</td>
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<tr>
<td>• Start the new cross-disciplinary groups within the R&amp;D department with KOS after six months, so that everybody involved has time to become interested.</td>
<td>KOS in cross-disciplinary groups. Some suggest that KOS should be arranged in the new cross-disciplinary groups within the R&amp;D department.</td>
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<tr>
<td>• KOS fits like a glove within the new cross-disciplinary groups of the R&amp;D department.</td>
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<tr>
<td>• You [Peter Cronemyr] should study the new cross-disciplinary groups within the R&amp;D department. Their performance and how they could be improved.</td>
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<tr>
<td>• It is important that we do not do as we did the last time [another process improvement initiative at ABB STAL] : only lists of things to do that are not carried out. KOS has to build on everybody’s own motivation.</td>
<td>Motivation. Involvement and participation without force from management is important if participants are to be motivated.</td>
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</table>
A strategic concern for Swedish industry is its international competitiveness. The ability to improve the product development capabilities is a key factor to strengthening the competitive position in a global economy.

ENDREA is a national research program to renew and strengthen research and education in engineering design and engineering management. ENDREA was established on October 10, 1996 by the Swedish Foundation for Strategic Research, SSF.

The mission of the ENDREA program is to enable the manufacturing companies located in Sweden to

- reduce lead-time
- improve quality
- increase flexibility in the product development process
- increase the performance/cost ratio

The ENDREA program encompasses the entire product realization process. The program has three focus areas:

- engineering design theories and methods (DTM)
- simulation and digital prototyping (SDP)
- engineering management (EM)

The ultimate goal of the program is to integrate these three areas, thereby achieving a holistic approach to product development. In order to promote a closer relation between the research projects and the visions and goals of the program ENDREA is subdivided into six clusters. This gives a better condition for a more active participation of senior people in the research and for synergies between the different projects.

The research and education in ENDREA are open to different theoretical approaches. The research is performed with a strong connection to Swedish industry and in an international environment. The doctors and licentiates who graduate from ENDREA are well equipped for substantial work within Swedish enterprises. Research and education within ENDREA deals with products that integrate mechanics, electronics, computers and software.