KTH Industrial Engineering
and Management

Decision making in concept phases

Towards improving product development processes

INGRID KIHLANDER

Licentiate thesis
Department of Machine Design
KTH, Royal Institute of Technology
SE-100 44 Stockholm

TRITA – MMK 2009:13
ISSN 1400-1179
ISRN/KTH/MMK/R-09/13-SE
ISBN 978-91-7415-375-0

TRITA – MMK 2009:13
ISSN 1400-1179
ISRN/KTH/MMK/R-09/13-SE
ISBN 978-91-7415-375-0

Decision making in concept phases – Towards improving product development processes

Ingrid Kihlander

Licentiate thesis

Academic thesis, which with the approval of Kungliga Tekniska Högskolan, will be presented for public review in fulfilment of the requirements for a Licentiate of Engineering in Machine Design. Public review: Kungliga Tekniska Högskolan, A425, Brinellvägen 83, Stockholm, on June 24, 2009, at 10:00.

Integrated Product Development
Department of Machine Design
Royal Institute of Technology
S-100 44 Stockholm
SWEDEN

TRITA - MMK 2009:13
ISSN 1400 -1179
ISRN/KTH/MMK/R-09/13-SE

Document type	*Date*
Licentiate Thesis	2009-06-24

Author

Ingrid Kihlander
(ingridk@kth.se)

Supervisor(s)

Margareta Norell Bergendahl
Sofia Ritzén
Jenny Janhager

Sponsor(s)

Volvo Car Corporation and Product Innovation Engineering program, PIEp

Title

Decision making in concept phases – Towards improving product development processes

Abstract

Successful concept decisions are crucial for product development organisations. Failure in the concept decision-making process means costly rework, requiring resources that could have been spent on innovative work with new products instead. This licentiate thesis tackles the concept decision-making process and how to improve it. The research presented here is the first part of a research project, with an action research approach, that will develop new supporting working procedures for concept decision making and thereby contribute to more successful products.

Empirical studies were conducted in Swedish industrial practice, particularly focusing one organisation, and it was found that concept decisions are not made at a certain point in time. Instead, many decisions and activities, on several organisational levels, were adding up to the concept decisions in the investigated organisations. The concept decision-making process was found to be *a web of interconnected activities, with many decisions integrated and embedded in the process*. It was also found that both formal and informal factors influence the concept decision-making process and main factors were identified as: *Project and product request*, *Supporting structures and routines*, *Individual competence and driving forces*, *Teamwork and company culture* and *Contextual circumstances*. These factors represent different perspectives, meaning on what level they influence concept decision making: *individual, team, project, organisation*, and *context*, and in order to create improvements in the concept decision-making process all levels have to be considered. The knowledge of the different perspectives has implications for how improvements should be designed.

Larger product developing companies do often have internally defined formal working procedures that prescribe how to develop products within the company. The thesis discusses how the internal working procedures relate to academic theory and to practice. It was concluded that internal formal working procedures has not been discussed in a sufficient way in earlier engineering design research. Furthermore, means for improving the concept decision-making process are discussed, and it was concluded, based on interviews with practitioners, that the strongest pragmatic means for improvement were developing *mindset* and applying *methods. Mindset* addresses the awareness, attitude and approach needed for management (and co-workers) working in early product development phases. *Methods* mainly addresses the need for having relevant supporting working procedures in general and templates for evaluation alternative solutions in particular. Finally, recommendations for future design of a template for evaluation alternative solutions are presented.

Keywords	*Language*
concept evaluation; decision making; product development	English

Preface

Many thanks to my professor, Margareta, always pushing forward in an inspiring way! I am very grateful for having the supervisor team of Sofia and Jenny, who contribute with the scientific rigour, hard work and encouragement to my research. They also took on the challenge of turning me, from an engineer working in product development solving very specific problems, into a research student working with research issues on a generalised level. Also, a special acknowledgement to Ernesto, who is my closest colleague in this business of pursuing a PhD - thank you for making me think on what I really strive for with my research. Gunilla, Diana, Anders, Lasse, Jens, Calle and Ailin – my valuable colleagues at Integrated Product Development, KTH. Thank you Vicki, for helping me to tidy up the English writing. Further, I would like to acknowledge the Product Innovation Engineering program, PIEp, for contributing to the research project. Thanks also to the activities and the fellow PhD students in the PIEp Research School.

This research would have not been possible without the support from my company, and especially the great support and encouragement I receive from the department of Painted Body Engineering. My department director Bengt, my manager Leo and my industrial supervisor Peter: you deserve a very special thank you - this would have not been done without you and confidence in me! Also, a great recognition to Mårten, Inger and Hans who have contributed in my Reference Group (together with Bengt, Leo, Peter, Sofia and Jenny), having fruitful discussions and always sharpening my focus on the industrial relevance. I would also like to mention all other colleagues at Volvo Car Corporation, with whom I have had several discussions in meetings, at the desk, at lunch, and in the corridors. I have always been met by encouragement, willingness to share - and to improve. My acknowledgments also to the Volvo Industrial PhD Program.

Finally, I am feeling a great gratitude for having my closest family, always supporting me, no matter what I would aim for: Mum, Sven, Bo, Malin and Henrik.

Stockholm, 2009-05-07

Ingrid Kihlander

List of appended papers

Paper A

Kihlander, I., Janhager J. and Ritzén S. (2008) "Challenges in Concept Decisions in Complex Product Development". In proceedings of the 15th International Product Development Management Conference, IPDMC, EIASM, June 29 - July 1, Hamburg, Germany.

Distribution of work between authors: Kihlander, Janhager and Ritzén had a close collaboration in all parts of the study. Kihlander had the main responsibility for the data collection, where Janhager supported Kihlander during the first interviews, and the writing.

Paper B

Kihlander, I. and Ritzén S. (2009) "Deficiencies in Management of the Concept Development Process: Theory and Practice". In proceedings of the 17th International Conference on Engineering Design, ICED'09, Design Society, August 24 - 27, Stanford, USA.

Distribution of work between authors: Kihlander performed the planning, conducted the interviews and made the analysis. Ritzén was involved in the analysis and writing.

Paper C

Kihlander, I. and Ritzén, S. (2009) "Concept Decisions – a Web of Interconnected Actions". In proceedings of the 16th International Product Development Management Conference, IPDMC, EIASM, June 7-9, Twente, the Netherlands.

Distribution of work between authors: Kihlander and Ritzén planned the study together. Kihlander performed the empirical data gathering, analysis and writing.

List of published papers not included in this thesis

Kihlander, I., Janhager J. and Ritzén S. (2008) "Dependencies in Concept Decisions in Complex Product Development". In proceedings of the 10th International Design Conference, DESIGN 2008, Design Society, May 19-22, Dubrovnik, Croatia

Gutiérrez, E., Kihlander, I. and Eriksson, J. (2009) "What's a good idea? Understanding evaluation and selection of new product ideas". In proceedings of the 17^{th} International Conference on Engineering Design, ICED'09, Design Society, August 24 - 27, Stanford, USA

Table of Contents

1 Introduction

Making wrong decisions in early product development[1] phases may have severe, costly consequences as for example extra tooling investments and engineering hours, but also cause frustration among management and co-workers. Therefore, this licentiate thesis investigates how concept decisions are made in product development projects and how management of concept decisions can be improved. *Concept decisions* are here considered as the early decisions in product development projects where a product developing organisation decides on what to pursue in the phases of detailed product development. The results presented in this thesis conclude the first part of a research project that aims to improve the concept decision process, through developing new supporting working procedures and thereby contributing to better concept decisions that will give more successful products.

The research project was initiated by Volvo Car Corporation and is carried out as an Industrial PhD project based at the department of Painted Body Engineering. The author is affiliated to the division of Integrated Product Development at KTH, the Royal Institute of Technology. Research at the division of Integrated Product Development deals with organisational and technical processes for efficient and effective development of innovative technology oriented products, services and systems. Their research is performed in close cooperation with industrial companies dealing with knowledge intensive solutions. The research project is also closely linked with the Product Innovation Engineering program (www.piep.se), a Swedish research and development program aiming for increased innovation capability in people and organisations.

The outline of the thesis is as follows. The *Introduction* includes the background for the research presented, problem description and research questions in order to guide the reader into what they will find in the thesis. In the chapter *Theoretical Framework* an overview is given of theoretical areas that were judged to have most relevance for the research presented. *Research Approach and Methodology* describes what approach and methodology have been used when planning, conducting and analysing the empirical studies. The *Summary of Appended Papers* presents short descriptions of each appended paper; the research results and how the papers have contributed to this licentiate thesis. In *Discussion* the empirical findings are discussed in relation to earlier research findings. In the final chapter, *Conclusions and Future Work*, contribution to theory and implications for companies are defined, and ideas for future work are presented.

1.1 Background

The main part of the product and lifecycle cost is committed during the concept development phase (Figure 1.2) (Ulrich and Pearson 1993; Ullman, 1997; Nevins and Whitney, 1989). This emphasises that concept evaluation and selection process is essential for a project to succeed, as selected concepts determine the direction of the detailed design phase (King and Sivaloganathan, 1999).

[1] Product development: " …a set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product" (Ulrich and Eppinger, 2008, p.2). Often modelled as a sequence of phases such as: *Planning, Concept Development, Detail Development* and *Industrialisation.* See section 2.1 Product Development for further details.

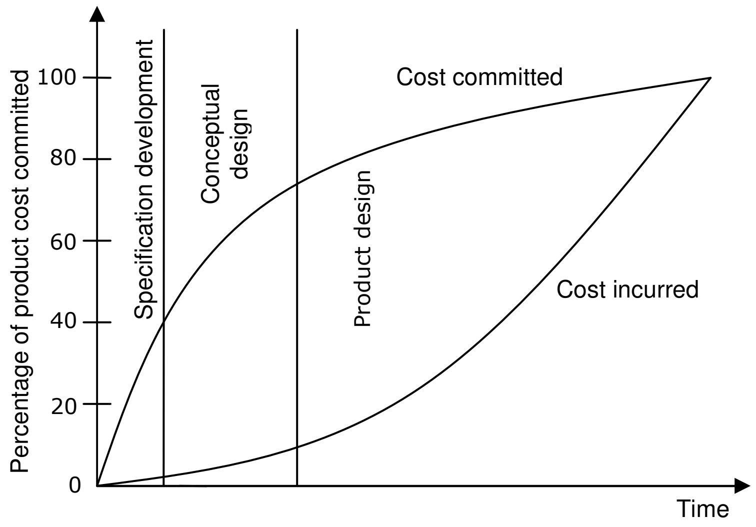

Figure 1.1: Manufacturing cost commitment during design, Ullman (1997)

Concept decisions involve balancing the right risks with the right opportunities. For a company, this could be an issue of surviving or not, since they are forced to make decisions based on very little information e.g. concerning innovative solutions already in the idea stage. Wrong concept decision can expose a company to higher risks in economic terms and can also cause badwill for the brand or company. Bad concepts can result in the customer not liking the product or some feature of the product (e.g. Marks, 1989) or even that the customer chooses products from a competitor instead and the company loses market shares. Bad concept solutions can also result in the customer discovering sheer design flaws and the company having to compensate for any pain and suffering (Gries, 2007). Even if "the badness" is discovered during the product development project, it will most likely result in rework of the concept and product (cf. Chin and Wong, 1999). Rework performed in product development projects cost large amounts of money in tooling investments and engineering hours – time and money that could instead have been spent on innovative development for future products. Besides that, rework can also cause a lot of frustration among the management and co-workers in the development team, which can result in decreased motivation and quality of the development work performed. This frustration was one of the personal starting points for the author when engaging in this research project.

Product development is a business of competition and the competitive situation for today's' automotive companies is extremely hard. There has been an overproduction for several years, and a widespread price competition exists in the automotive business, which is also deeply affected by the present economical situation, involving big losses and co-worker lay-offs. When looking forward, the importance of making good concept decisions is even more emphasise under these circumstances.

1.2 Problem description

Decision making on concepts is challenging due to the limited knowledge and insufficient information available early on in a product development projects, combined with the uncertain and abstract nature of the product concepts considered. Whilst there is more potential to influence the product early in the process, there is less knowledge regarding the design problem. This has been called *The Design Process Paradox* (Ullman, 1997), seen in Figure 1.2.

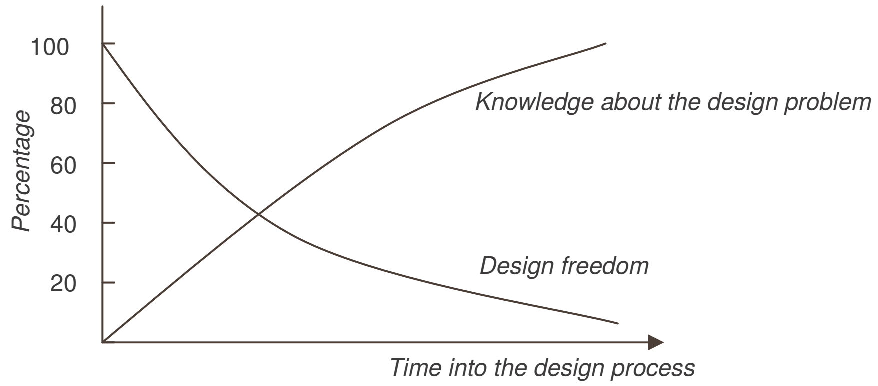

Figure 1.2: The Design Process Paradox (Ullman, 1997)

The need for research on decision-making within engineering design was stated earlier by e.g. Dwarakanath and Wallace (1995, p1): "The process of decision-making is not understood completely, so more research into how decisions are actually made is needed". Andersson (2003, p. 22) agrees: "It seems as this is an important and promising area for research, consequently bridging the gap between design research and psychological and cognitive research on human judgement and decision-making (e.g. human behaviour in choice situations)."

Large companies, such as Volvo Car Corporation, do have supporting structures and supporting working procedures for the product development process, for example process maps, instructions and role descriptions. They also have many experienced and ambitious co-workers at their disposal. *However, this is not enough. Common practice in industry reveals that companies, in spite of the available support, still suffer from a great amount of rework due to wrong concept decisions.* The author's experience is that existing formal concept selection methods do not entirely fulfil the needs of concept selection in an industrial context, which also has been noted by Salonen and Perttula (2005).

Therefore, with the problem described from both theoretical point of view and from the perspective of industrial practice, the purpose of the research project and licentiate thesis will be presented in the next section.

1.3 Purpose

The research presented in the thesis is based on results from the first part of an overall research project. The overall research project will contribute to greater understanding of the concept decision-making process in industrial settings and the project's purpose is to develop supporting working procedures for managing the concept decision-making process in order to contribute to more successful products in industry. The purpose of the research presented in this licentiate thesis is to contribute to better understanding of and explore possibilities for improvements of the concept decision-making process in industrial settings.

The research project, organised as an industrial PhD-project, runs over five years and is divided into two phases. The first part of the project is explorative and descriptive, and the results are reported in this licentiate thesis. The research presented here discusses empirical results from three studies in two industrial companies, which will form a base for the future development of improved working procedures for concept decision-making process, and to implement a change in the case company. Therefore the purpose of the first half was to identify how concept decisions are made and what influences and characterises these decisions in early project phases. Another purpose of the work presented here was to discuss how the concept decision process could be improved. During the second half of the research project, supporting working procedures and a management model will be developed (based on empirical findings as well as available theories), tested and evaluated in the Volvo Car Corporation's organisation.

The overall approach of the research is to create improved supporting working procedures but also enhanced understanding and awareness among the co-workers in the organisation in order to improve the concept decision-making process at the company (Figure 1.3) bearing in mind that organisations are considered to be composed of structure, technologies and social aspects (Lenéer-Axelsson and Thylefors, 1991).

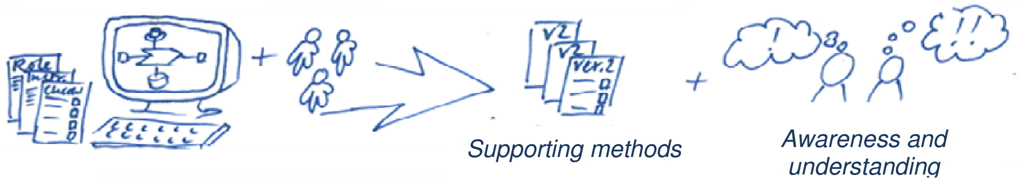

Figure 1.3: A visualisation of the purpose of the research project

The work presented in this thesis turns firstly to large companies that have product development as a core activity, and that have moved beyond the first steps of modelling product development processes but still face a challenge of fully deploy appropriate models and processes. The research project was initiated by, and has its base at, Volvo Car Corporation. Consequently, the perspective and starting point used in this work is global product development based in Swedish industry. However, the author aims to present and discuss the research findings in a way that make them interesting, relevant and valuable for others as well. Also, it should be stated that the point of departure for this research is the product developing individuals and teams in the organisation, thus the research has had a bottom-up approach in contributing to the management of product development processes.

The research presented will add to the existing body of research on decision making within the engineering design research area (see for example Badke-Schaub and Gehrlicher, 2003; Hansen and Andreasen 2004; Eriksson, 2009).

1.4 Research questions

The focus of the research is decision making in the context of knowledge intensive and complex development processes, and several researchers point out challenging situations that product development teams have to face when they develop concepts and solutions. Roozenburg and Eekels (1995) emphasise the importance of the concept decisions through stating that a weak concept never can be turned into an optimum detailed design. This resembles, but still understates, the complexity and challenges experienced by the author in situations of making concept decisions. An assumption, based on the author's industrial experience of this work, was that there are other factors that influence the concept decision process, besides the ones taken care of in the academic theories or in the companies' prescriptive routines, which has also been noted by Gutiérrez et al (2008). Emphasis has therefore been put on trying to find out, through empirical studies, how those decisions are actually made.

It has already been stated that the practice today is not good enough. What more does it take? Why does the practice not work well enough when there are so many controls, theories and supporting methods available in literature, and routines and rules available in practice? Research questions are questions for which no answer yet exists (Blessing, 2008), and they should be interconnected, meaning that they are related and forming a coherent whole (Robson, 2002). The inquiries above have been summarised in two research questions:

RQ1: *What is characterising and what factors are influencing the concept decision-making process in large companies, considering the whole system composed of structure, technologies and social aspects?*
RQ1 aims to find out, based on empirical studies, what characterises and influences the concept decision-making process, since one assumption is that there have to be *more* influencing factors than the ones usually taken care of in formal management models and process.

RQ2: *How should the concept decision-making process be managed in practice, and what pragmatic improvements are found, considering the new knowledge on characteristics and factors?*
The answers to RQ2 aim to support how to manage the concept decision-making process in practice, considering the holistic picture of influencing factors. The answers to RQ2 will also address means to improve the concept decision-making process, based on results from empirical studies, best practice and theoretical state of the art.

In order to guide the reader the Table 1.1 provides an overview of what research questions that are addressed in each paper.

Table 1.1: How the papers address the research questions

	Paper A	Paper B	Paper C
Addressing RQ1	●	●	○
Addressing RQ2	○	○	●
●= *significantly,* ○= *moderately*			

2 Theoretical framework

The work presented in this licentiate thesis is mainly based on contributions from the theoretical areas Product Development, Engineering Design and Decision Making. The theoretical framework used for the research is modelled in an Areas of Relevance and Contribution-diagram (ARC-diagram) (Figure 2.1). The ARC-diagram is based on a model developed by Blessing (2008) and illustrates the theoretical areas that are considered to be relevant for the research, and to what areas the research aims to contribute to. The question mark symbolises theoretical areas that might be discovered along the way in the research project and that therefore should be incorporated in the research work.

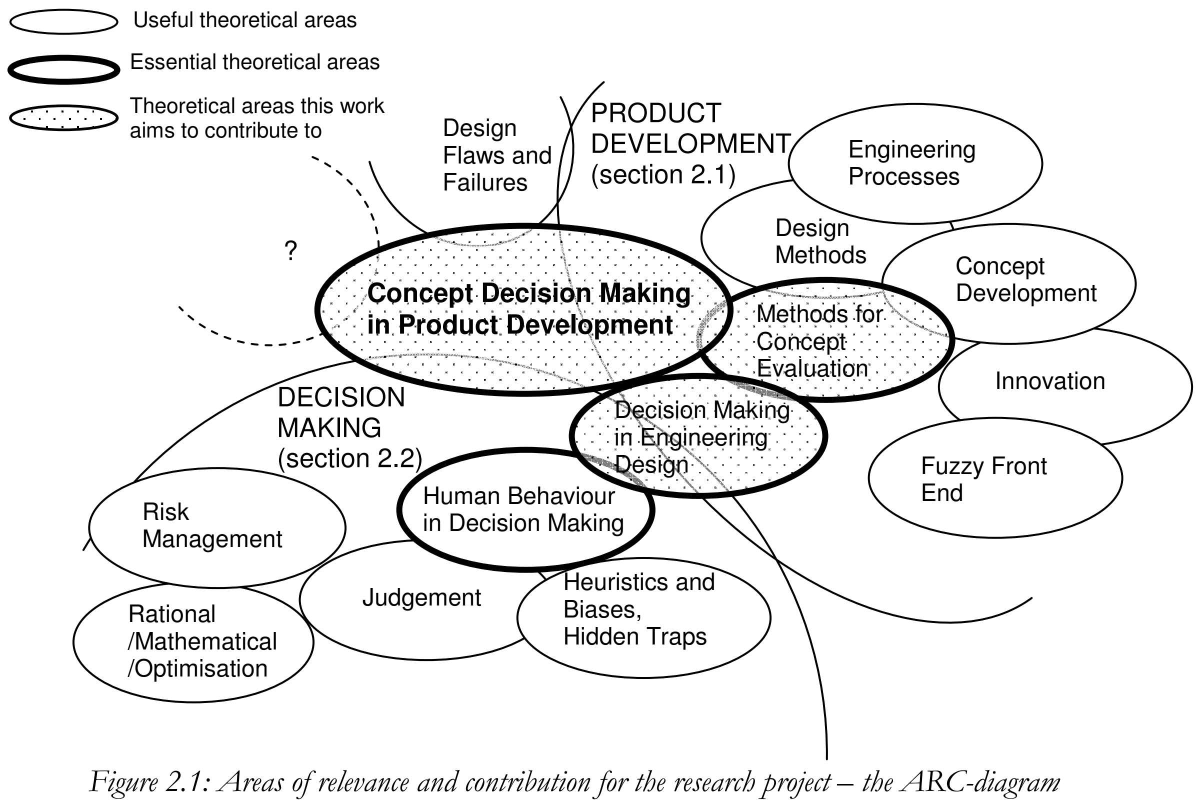

Figure 2.1: Areas of relevance and contribution for the research project – the ARC-diagram

2.1 Product development

A definition of product development is, according to Ulrich and Eppinger (2008, p.2): "…a set of activities beginning with the perception of a market opportunity and ending in the production, sale and delivery of a product". In the PDMA Handbook (2005) product development is defined as: "The overall process of strategy, organisation, concept generation, product and marketing plan creation and evaluation, and commercialisation of a new product". There are a fair number of textbooks for practitioners and students on the subject of product development and these books present similar models of the product development process, showing models of a sequence of phases (e.g. Roozenburg and Eekels, 1995; Pahl and Beitz, 1996; Ullman, 1997;

Ulrich and Eppinger, 2008). Taylor (1993) reflects on the fact that several models of product development processes are presented in theory (i.e. the absence of *one* model universally adopted) and that this must be indicative of a fundamental difficulty when it comes to defining and describing product development. However, the suggested models have the same base structure beginning with clarification of the task, conceptual design, embodied design and industrialisation. It starts with an initial need (the design problem) and the product is developed and verified to satisfy this need. An example is the generic product development process proposed by Ulrich and Eppinger (2008) including the six phases: *Planning, Concept Development, System-Level Design, Detail Design, Testing and refinement* and finally *Production Ramp-up* (Figure 2.2).

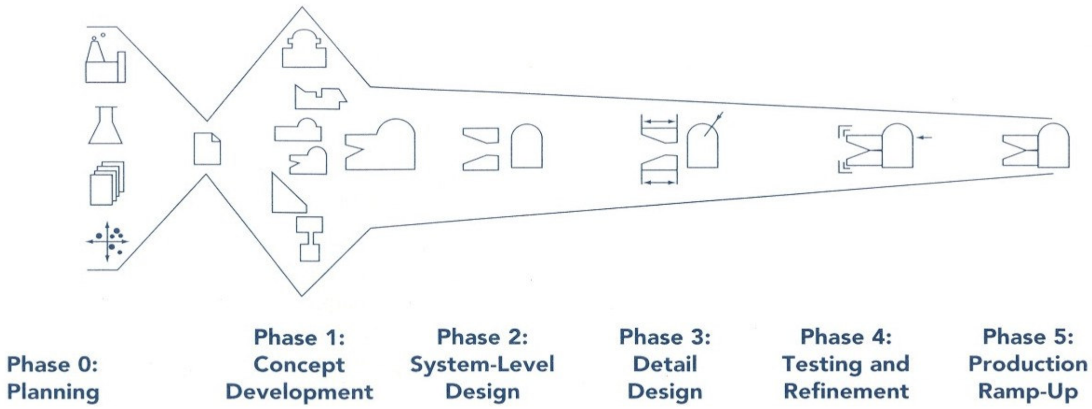

Figure 2.2: A generic development process (Ulrich & Eppinger, 2008)

Product development consists of many activities, using several different competences, which have to be planned and correlated. Hence, it is a multi-disciplinary process and *Integrated Product Development* is a managerial approach where parallel development activities and cross-functional teams contribute to more efficient product development (Andreasen and Hein, 1987).

Step-sequenced models of product development processes have received criticism of being rigid and non-dynamic. Engwall (2003) asserts that the models do not support knowledge enhancement and utilisation during the development project and therefore serve as a poor support for innovation. Engwall (2003) also states that the product development models are not designed to handle a changing environment since these development models presume that all relevant knowledge is available at in the start-up of the project and can be specified in targets and requirements. However, Cooper (2008) emphasises that the stage-gate is not a linear process disregarding the traditional illustration or a rigid system, and it should be considered more as a "playbook" that should be adapted to each specific situation.

Innovation and Fuzzy Front End

An important perspective on product development is innovation and innovativeness. There is extensive literature on innovation and several definitions of the characteristics of innovations are available (see for example the literature review by Garcia and Calatone, 2002). According to the PDMA Handbook (2005) the innovation process may be divided into three areas: the Fuzzy Front End (FFE), the New Product Development (NPD), and Commercialisation. The FFE is activities that come before the more formal and well-structured NPD process, such as the one described in Figure 2.2. The FFE is often chaotic, unstructured, and unpredictable and there have been several suggestions of how to support management of the FFE through different approaches (e.g. Khurana and Rosenthal, 1997; Khurana and Rosenthal, 1998; Reinertsen, 1999; Koen et al, 2001). It has also been stated that in these surroundings it is important to foster intrapreneurs (Menzel et al, 2007) and to have an open culture and climate in the organisation to increase the likelihood of innovation (Ekvall, 1996; Nicholson, 1998; van Riel et al, 2004).

Design Methods in general

According to Roozenburg and Eekels (1995), a method is always referring to an action and is the consciously applied diachronous structure of an action process. In literature the use of design methods is suggested in order to improve product development work, and a large number of structured supporting models and methods (both at overall level but also on a more detailed level) are proposed. An example benefit achieved when using structured supporting methods is encouragement of the integration of – and communication between - different competences in product developing organisations (e.g. Norell, 1992; Wright, 1998). Structured methods also serve the purpose of ensuring important issues are remembered, documenting decisions for future references, educating of new product developers, clarifying decision basis and reducing unconfirmed decisions (Ulrich and Eppinger, 2008). On the individual level structured methods and procedures can help the designer to think of other solutions than the first one that appears. The methods will also support the designers in transferring the thinking onto paper, e.g. using diagrams and charts, i.e. externalise the design thinking, which frees cognitive resources for intuitive and imaginative thinking (Cross, 2000).

Previous research on supporting methods and tools has concluded that in order to be utilised the method has to fulfil certain requirements. Norell (1992) asserts for example that: the methods should to be easy to learn, understand and use; they should incorporate accepted, non-trivial knowledge within the focused area; and be developed for use by several professions and thereby contribute to creating a common frame of reference. Supporting methods should also, according to Pahl and Beitz (1996), reduce hard workload, save time, prevent human error, foster inventiveness and understanding, and help to maintain an active interest. Furthermore, the way the supporting methods are implemented has also been identified as crucial for success (Norell, 1992; Beskow and Ritzén, 2002).

Utilisation of such supporting methods has, however, not been highly developed. An investigation of utilisation of methods in Swedish industry stated, that 30% of the companies responding in the survey used an evaluation method at some point and only 15% of the companies replied that they used evaluation methods on a regular basis (Janhager et al, 2002). The same observations of a low degree of utilisation of supporting methods in the concept phase are also reported from other countries, such as the UK and Finland (Araujo and Benedetto-Neto, 1996; Salonen and Perttula, 2005). Hein (1994) elaborated on the issue of the low degree of implementation of systematic design methods in industrial practice, and emphasised the need-driven practice, as built rather on a rationalisation of what is currently the practice supplemented by modern buzzwords than an in-depth knowledge of available theoretical methods.

Concept development

The concept development is one of the initial phases in the product development process. The activities in the concept development phase aim to generate several concept alternatives, evaluate these alternatives based on all relevant prerequisites and finally select one or more concepts for further investigation or development (e.g. VDI, 1986; Pugh, 1990; Roozenburg and Eekels, 1995; Pahl and Beitz, 1996; Ullman, 1997; Ulrich and Eppinger, 2008). It is also described that a concept decision is a single point in time and that the team or the individual only has one concept decision to consider at the time (Roozenburg and Eekels, 1995; Ullman, 1997; Cooper, 2001 and Ulrich and Eppinger, 2008). An example of an illustration of the concept development is the front-end activities according to Ulrich and Eppinger (2008), which can be found in Figure 2.3.

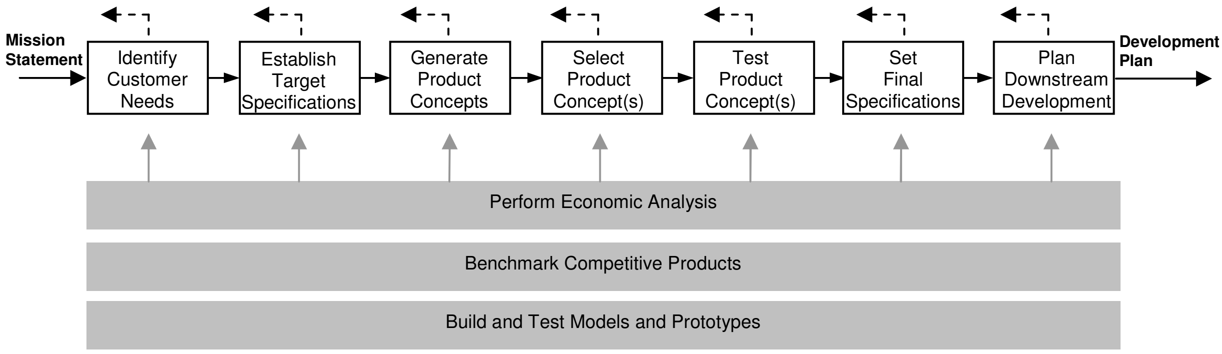

Figure 2.3: The front-end activities comprising the concept development (Ulrich and Eppinger, 2008)

Empirical findings have, however, found that concept development can include not only the concept stage in the product development process, but also the preceding activities, such as the 'pre-program planning phase', i.e. covering both the unstructured Fuzzy Front End and the more structured product development (Backman et al, 2007, Setterberg, 2008).

In the engineering design community the word *concept* is usually described as an approximate description of the technology, working principles, and form of the product (Ulrich and Eppinger, 2008) or as an idea that is sufficiently developed to evaluate the physical principles that governs its behaviour (Ullman, 1997). A concept should be developed far enough to be able to ensure that the proposed product will operate as expected and that, with reasonable further development, will meet targets set (Ullman, 1997). Hansen and Andreasen (2002), however, call attention to the fact that a good concept has consequences in three dimensions (a profitable business, a good product, and a manageable product development process) and that a concept can be seen from two sides: need/market-oriented and design/realisation-oriented. Hansen and Andreasen (2002) emphasise that a concept has a dual nature and therefore the understanding of concepts should include both *the idea with* and *the idea in* the concept. This resembles the PDMA definition where the combination of customer benefits and the technology needed is stated (PDMA, 2005).

In the extensive literature presenting concept development, many definitions and expressions are used (e.g. concept development, generation, evaluation, selection, screening, scoring, comparing and eliminating) but no unified definitions were found. For example the expressions are sometimes used as synonyms to each other, and sometimes as sequential steps in an overall concept development activity. Despite the variety of wordings the authors do agree that concept development consists, in the main, of a diverging process that includes generation and development of alternative concepts, and a converging process. The generation and exploration in the diverging process should preferably use input from different sources, both internal and external (Roozenburg and Eekels, 1995; Krishnan and Ulrich, 2001). The diverging concept generation is followed by a converging process (Figure 2.4) where different alternatives are evaluated against defined criteria, compared, refined, and finally one (or more) concept is selected for further development (Ulrich and Eppinger, 2008). The research presented in this thesis focuses on the later, converging part of concept development, ending up in the *concept decision*, selecting the preferred concept solution(s) to pursue into detailed development. *Concept development* will be used in this thesis to describe the overall process that ends up with chosen concept solution(s).

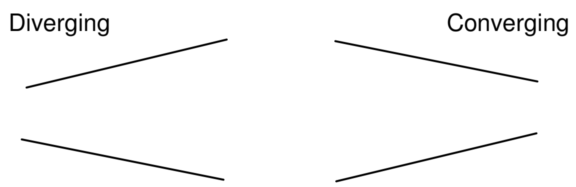

Figure 2.4: The concept phase has a both divergent and convergent character

Methods for concept evaluation and selection

How to make the specific concept decision is seldom explicitly elaborated in engineering design literature but rather seems to be included in the concept selection, with the decision as an obvious result of a concept evaluation. Concept selection means filtering of concepts in a rational way and not necessarily the making of a final concept selection (Avigad and Moshaiov, 2008).

The selection of the concept can be done in several (more or less structured) ways, and it could be said that even if only one concept is generated the team is using a method: choosing the first concept they think of (Ulrich and Eppinger, 2008). Examples of other methods for concept selection that may be used are: the decision is handed over to the customer (external decision), an influential team member makes the decision (product champion) or by intuition ('gut feeling') (Ullman, 1997; Ulrich and Eppinger, 2008).

More analytical approaches have also been recommended as decision support in early development phases. Gandy et al. (2006) demonstrated how to use expert information and Monte Carlo simulations, Saaty (1990) proposed the Analytical Hierarchy Process (AHP) and Ayag and Özdemir (2009) recommended the Analytical Network Process (ANP) as decision support. In the AHP and the ANP the decision situation (including goals, attributes and stakeholders) is modelled in a hierarchy (AHP) or as a network (ANP) to provide an overall view of complex relationships in the decision situation. Nevertheless, Ayag and Özdemir (2009) note that the risk of decision-maker bias towards any particular alternative cannot be ruled out while applying these models.

In engineering design literature it is agreed that structured evaluation methods are preferable in the concept development process. According to Pugh (1990), structured selection methods can be used to reach a controlled convergence, since the methods provide a more rational (using objective criteria) and open procedure, which decreases personal bias (Cross, 2000; Andersson, 2003; Ulrich and Eppinger, 2008). The evaluation methods may or may not include a decision rule, meaning that the method establishes the 'best' alternative or perhaps just supports assessment of the overall value of the alternatives - i.e. not supporting the decision maker in the last step of the process (Roozenburg and Eekels, 1995).

Even though a variety of evaluation methods have been proposed by the authors of textbooks on engineering design, they are quite united in recommending the use of a decision matrix for evaluation performed in a team (Pugh, 1990; Roozenburg and Eekels, 1995; Pahl and Beitz, 1996; Ullman, 1997; Cross, 2000; Ulrich and Eppinger, 2008). There are different sorts of decision matrix methods but they mainly include the following steps: identify criteria for comparison, maybe weighting the criteria; select the alternatives to be compared; generate scores and compute a score. A well-known example is Pugh's evaluation matrix, where different alternative solutions are compared to chosen datum and then rated, better (+), worse (-) or the same (S) on each chosen (non-weighted) criteria. However, concept selection methods have been criticised for not treating the effect of couplings between decisions in a proper way (Dwarakanath and Wallace, 1995; and King and Sivaloganathan, 1999).

In order to reach an effective evaluation, the alternatives and criteria for evaluation must be in the same language, have the same level of abstraction (Ullman, 1997), be deduced from the product specifications and be agreed (Pugh, 1990). Team members' knowledge and understanding of the different concept alternatives may also affect the evaluations (Reidenbach and Grimes, 1984). Empirical tests have shown that respondents may say they understand the concept when in fact they really do not; and that if they have low knowledge of the concepts, they may be basing their evaluations on information other than what is presented in the concept description (Reidenbach and Grimes, 1984).

A number of authors have provided overviews of evaluation or selection methods (e.g. Baker and Albaum, 1986; Otto, 1995; Ullman, 1997; King and Sivaloganathan, 1999; Andersson, 2003). They have investigated the different methods regarding e.g. ease of use; the cognitive effort required and treatment of multiple attributes; the weighting of different attributes; and coupled decisions. The different overviews use different patterns for labelling the methods. For example, Pugh's evaluation matrix has been labelled in different overviews as: *relative* (Ullman, 1997), *graphical* (King and Sivaloganathan, 1999) or *equal weight heuristic* (Andersson, 2003). Besides the methods overviews, comparisons between different evaluation and selection methods have been made in previous research:

- Most methods King and Sivaloganathan (1999) have reviewed can handle multiple attributes in a decision, although the QFD-matrix represents this facility with greatest clarity due to its graphical template.
- Pugh's selections matrix was considered to be the method most easy to understand and to use (Weiss and Hari, 1997; King and Sivaloganathan, 1999; Salonen and Perttula, 2005).
- For unbiased and honest concept selection, Weiss and Hari (1997) recommended Pugh's evaluation method, but said that when any kind of biases are present in the team, a semi-quantitative, sophisticated selection procedure should be chosen instead, as it will increase the odds that the team's proposal will actually be accepted by external approving channels.
- Salonen and Perttula (2005) stated that simplicity has its price since Pugh's method considers neither importance of different criteria, nor any difference in magnitude (how much better, how much worse). King and Sivaloganathan (1999) therefore asserted that Pugh's method is suitable to eliminate highly unfeasible concepts.
- Salonen and Perttula (2005) highlighted the critique against rating matrices since they include their dependency on arbitrary weights of requirements and consideration of only linear preferences of the decision maker.
- The Analytical Hierarchy Process (AHP) was complex and time consuming, but more likely to handle decision-maker bias (Salonen and Perttula, 2005).
- None of the concept selection methods that King and Sivaloganathan (1999) reviewed gave adequate provision for the effect of coupled decisions, which points to a shortfall since most real-world problems include a great many interconnections.
- When two or more concepts are found to be close, the intuition of the project manager will be the best selection tool (Weiss and Hari, 1997).
- Weiss and Hari (1997) and Baker and Albaum (1986) concluded that the selection method has to be adapted to the circumstances, such as the type of product involved, the nature of the company, its existing product line, markets and goals.

In addition to the overviews and comparisons presented in literature there are several researchers who have presented what they consider as addressing a need that is not answered by the available evaluation methods. Such an example is Justel et al (2007) who have presented a method that supports companies in assessing the innovation potential of product concepts and selecting the concepts with a greater probability for success, taking into account the degree of novelty of product concepts and their potential for success in the market.

Previous empirical findings on alternative solutions for evaluations

Evaluation methods are designed with the assumption that different alternatives are generated and that the method will be used for evaluating these alternatives and thereby identifying the best one(s). However, empirical findings show quite another picture and it is reported that often only one or a few alternatives are generated (Blessing, 1994; Chin and Wong, 1999) and that little time is spent on the aspect of criteria importance (Girod et al, 2003). When only a few alternatives are generated, the strategy of performing an extensive evaluation of different alternative solutions cannot be used. Furthermore, in evaluation of a concept it is assumed that participants act objectively, but it has been observed that designers might get *fixated on* or *attached to* a certain solution principle and will stick to this principle solution for as long as possible (Jansson and Smith, 1991; Blessing, 1994; Cross, 2006).

Iterations in the process

When the product development process is depicted on an overview level, it shows the process as rational and step-wise. Empirical findings state that step-oriented design methodologies are rarely followed by practical designers (Stempfle and Badke-Schaub, 2002) and that some experienced designers are able to develop good solutions early in the design process without employing methodological strategies or conducting systematic analysis of important information (von der Weth, 1999).

However, study of prescriptive models available in literature (on product development in general and concept development in particular) shows that the processes are often noted as iterative. Roozenburg and Eekels (1995) have a feedback loop from the decision step to both analysis and synthesis in the basic design cycle; a cyclical iteration between generation and evaluation is shown in several models (Pugh, 1990; Ullman, 1997; Ulrich and Eppinger, 2008); and additional concept generation and refinement may be initiated (Ulrich and Eppinger, 2008). Refinements of any one of the steps - by iteration on a higher information level - should be made whenever necessary (Pahl and Beitz, 1996), and in VDI 2221 (1986) an assumption is made that the design steps have been worked through in an iterative manner before a decision about the optimum overall solution. Roozenburg and Eekels (1995, pp.23-24) summarise that"…in product development everything has to do with everything and everything proceeds into everything…", thus iterations are a necessity.

Set-based as an alternative to point based development

The assumption for the evaluation methods mentioned above is that that several alternatives are generated. A challenge for the development team is to decide when to narrow down to a single concept. Ideally, a designer would know enough about each concept at the decision point to choose one and put all possible resources into developing the chosen concept (Ullman, 1997). The authors mostly speak about the *one concept* (VDI, 1986) to be developed in detail, but sometimes they use a saving clause stating that maybe the selection should end up in "one (or more)" selected concept(s). It is notable that there has been a change during the years in Ulrich and Eppinger's (2008) overview of the front-end activities (Figure 2.3) where the figure has been updated: "Select a Product Concept" (up to 2nd ed.) is now replaced with "Select Product Concept(s)" (from 3rd ed.). The traditional design practice, identified as point-based, tends to quickly converge into a solution, a point in the solution space, and then to modify that solution until it meets the design objectives (Sobek et al, 1999).

As an alternative to the point-based strategy, set-based concurrent engineering has been discussed based on studies of the successful development at Toyota (e.g. Ward et al, 1995; Sobek et al 1999; Morgan and Liker, 2006). One of the basic ideas of working with sets is to avoid time-consuming and costly iterations that can appear if it turns out that the solution, selected early in point-based design, is not meeting the objectives. Instead, Toyota's designer thinks about sets of design alternatives, found within the solution space, rather than pursuing one alternative iteratively in order to avoid work on solutions that must later be changed (Ward et al, 1995). In the set-based approach certain decisions are delayed longer, yet Toyota may have the fastest and most efficient vehicle development cycles in the industry (Sobek et al, 1999). "The manager's job is to prevent decisions from being made too quickly… but once a decision is made, we change it only if absolutely necessary. " quoted from Toyota's General Manager of Body Engineering by Morgan and Liker (2006, p.39).

2.2 Decision making

"Decision making is like talking prose – people do it all the time, knowingly or unknowingly" (Kahneman and Tversky, 2000). A *decision* is the commitment to an action whose aim is producing satisfying outcomes, whereas *decision making* is the process of solving a particular type of problem (Yates, 2001). Decision making is a vast area that can be treated from several perspectives and scientific approaches, such as psychology and cognition that deal with the human behaviour and cognitive processes, or rational mathematical areas where decision making always strives for maximized, optimised utility. The work presented here is not aiming to explore new ground regarding decision making for the scientific areas of psychology or mathematics. Instead, it focuses on to strengthen the area of engineering design and enhance the knowledge and understanding of human decision making from engineering design point of view, using theories from other theoretical areas.

Classical rational decision making (meaning when decision making is striving for maximum utility, not considering the effort and cost of doing the information search), requires a complete information search and is based on the following prerequisites, according to March (1997):

- Knowledge of alternatives: decision maker has a number of alternatives;
- Knowledge of consequences: decision maker knows the consequences of alternative actions;
- Consistent preference ordering: decision maker has consistent values used in the comparisons;
- Decision rule: decision maker has decision rules that are used to select a single alternative.

However, March (1997) points out that classical normative decision theories underestimate the interactive conflicts, confusions and complexity inherent in actual decision making in organisations, since organisations are open systems, which include many actors and coupled decisions. Many things are happening at once in an organisation, and they affect each other, meaning that decisions may be coupled but not necessarily coordinated (March, 1997). The organisational and social environments where decision makers act will determine the consequences they will anticipate, and the ones they will not; which alternatives they will consider, and which ones they will ignore (March and Simon, 1958). Many decisions in organisations have both logical and political aspects, and decision making is not a neutral event since it generally takes place in a force field in which different preferences and different definitions of social reality play a role (Koopman and Pool, 1991; Eisenhardt and Zbaracki, 1992).

Due to people's limited knowledge, ability and capacity of information processing it is stated that humans are rational only within certain limits and that decision makers stop the information search when they find an alternative that is good enough (Simon 1955; Simon 1956). Only in exceptional cases is the decision maker concerned with discovery and selection of the optimal alternative (March and Simon, 1958). It has also been found that individual preferences are not stable, but instead contingent on task demands (e.g. Payne, 1982; Bettman et al, 1998). Further, the individual decision maker can be affected by psychological traps and biases that can interfere in the decision-making (e.g. Gilovich et al, 2006; Hammond et al., 2006), such as *anchoring* where disproportionate weight is given to the first information that is received in the decision situation. Finally, factors such as intuition (Patton, 2003) and emotions (Zeelenberg et al., 2008) have been identified as being a part of individual decision making. Patton (2003) asserts that a combination of intuition, logic and emotions guide individuals to operate at an effective level, and Zeelenberg et al. (2008) emphasise that emotions help in decision-making since emotions exist for a reason – namely, guidance and prioritisation.

Based on empirical studies on decision-making processes, Nutt (1984) stated that nothing in his empirical findings remotely resembled the normative methods described in literature. Instead, he identified five types of decision-making processes: the historical model, the off-the-shelf, the appraisal, the search, and the nova process types. These processes differed in their approach to idea generation and process-management rationale. Most decision processes were found to be solution oriented, which seemed to restrict innovation, limit the number of alternatives considered, and perpetuate the use of questionable tactics. For example, the nova process (observed in 15% of the cases studied), was the only process type with activity in the conceptualisation stage aiming to find new innovative solutions (Nutt, 1984). Furthermore it is stated that managers should also stress idea creation and implementation, use different sources and identify more than one alternative (Nutt, 1999; Tatum et al, 2003).

Decision making on technical solutions

In their studies in product development Dwarakanath and Wallace (1995) have observed two main types of decision-making processes. The first type corresponds to the evaluation methods available in the literature, meaning that several alternatives were generated and evaluated in parallel against defined criteria. In the second type an alternative was evaluated as and when it was generated. After the alternative was evaluated, it was either modified or a new alternative was generated, showing a strongly coupled process of generation and evaluation (Dwarakanath and Wallace, 1995). The iterative, not necessarily stepwise, connections between evaluation and synthesis have also been observed by Suwa et al (2000) even though having several alternatives is recommended (Eisenhardt, 1989a). When studying the design process, Badke-Schaub and Gehrlicher (2003) defined five *patterns* of decision making in product development: leaps, loops, cycles, sequences and meta-processes. Leaps and loops were identified as being less successful than the three step-sequential patterns (cycles, sequences and meta-processes) and should thus be avoided. However, 47% of the decisions observed in the study were identified as belonging to the two less successful patterns (Badke-Schaub and Gehrlicher, 2003).

Hansen and Andreasen (2004) have identified a number of differences between their empirical findings and guidelines on design decision-making in engineering design literature. Instead of being made on a single occasion, they have found that decisions evolve during a period of time, and the design engineers concerned are making *tentative decisions* on the way, using criteria and information available at each tentative decision situation. López-Mesa and Chakrabarti (2007) further identified *implicit decisions* during the process which were results of actions, as well as inactions. Hansen and Andreasen (2004) also reflect on the complex situation in industrial practice, where there are in fact decision makers both inside and outside the design project, which results in different stakeholders acting as decision makers and thereby influencing the design process and its result. Corresponding to this, Ng (2006) criticises step-oriented engineering design methodologies since they lack traceability and do not consider the minor design decisions made throughout the design process before leading to the design solution.

Literature on evaluation methods recommends doing evaluation in teams. However, when working in teams additional hindrance may appear. Groups with members with long experience of design in industry tend to be impatient 'to get on with it' and may consider that a procedure holds them back from arriving at a solution (Pugh, 1990). Consensus is often difficult to obtain, but may be required to reach a decision in a team (Ullman, 1997).

Decisions made intuitively are also considered within literature of engineering design. Roozenburg and Eekels (1995) state that most design decisions are made with elements of intuition, and that people *have* to simplify a situation to be able to reach a decision, or else there would be no progression in the design process. Especially in early project phases, information of product concepts is insufficient, and thus decisions are made using qualitative information, judgments and incomplete evaluations (Blessing, 1994; Ullman, 1997; Chin and Wong, 1999). Ullman (2002) emphasises that there are no *right* answers, only *satisfactory* answers, and that a certain amount of noise exists (i.e. any factor that you cannot or choose not to control) in real-world decision-making.

Thus there are examples of authors that propose methods that are based on psychology and sociology combined with rational mathematical methods (e.g. Ahn and Dyckhoff, 1997; Ullman, 2002; Gidel et al, 2005). Ullman (2002) proposes a 12 step method which includes the following phases: *prepare the decision-makers* (steps 1-2), *clarify the issue* (steps 3-4), *develop criteria* (steps 5-7), *generate alternatives* (step 8), *evaluate alternatives* (steps 9-11) and *decide* (step 12).

When investigating decision-making in the Fuzzy Front End of discontinuous innovations Reid and de Brentani (2004) identified three critical interfaces - boundary, gate-keeping and project reflecting the information flow inward from the environment to the individual (boundary interface), and then inward from the individual into the organisation (gate-keeping interface), and finally from the organisation to a specific project. The first two interfaces are on the individual level (the individuals play different roles in the two interfaces) and the third interface is on the organisational level, with management acting as decision makers.

Which concepts find their way through the process may be affected in different ways. Weiss and Hari (1997) reported potential problems of passing the decision through local and higher management. Furthermore it has been observed that the origin and drivers of the concepts - such as technology or market - can also have an affect in so far as technology-driven concepts receive more support in a technical organisation (Backman et al, 2007).

It has been noted earlier that meetings in product development organisations are not usually used as decision points (e.g. Bragd, 2002; Christiansen and Varnes, 2006; Christiansen and Varnes, 2007). When following an industrial project, Bragd (2002) found that the meetings were used for screening the status and keeping the pace in the project and not for decision making. In studies of gate meetings in development projects, it was reported that few rational decisions were made in the official meetings. Instead, the gate meetings became an arena for justification of decisions already made and the gate system used as a signal and symbol for rational behaviour (Christensen and Varnes, 2006). Additionally, the power was found to be *displaced* into the templates used, signalling what the management consider as important (Christiansen and Varnes, 2007).

3 Research Approach and Methodology

This chapter describes the approach and methods used when conducting the research presented in this thesis. The chapter starts by presenting the approach (*Action Research*) and continuous with presenting the methodology (*Design Research Methodology*) of the overall research project.

3.1 A research project with an action research approach

The overall research project uses an action research approach, a method developed in the field of sociology and defined by research being conducted simultaneously with action in practice. An important statement from the creator of action research (Kurt Lewin) is that research should be conducted with the aim to create value for those who act in the context that is researched (e.g. Westlander, 1999). It is the relationship between the researcher and the change in practice that distinguishes action research from other research. Collaboration between researchers and those who are the focus of the research is typically seen as central to action research (Robson, 2002). If the researcher only evaluates the change in practice or the change progress it is not enough to label it as action research. Minimum requirement is that the researcher brings knowledge and develops the involved participants understanding of the situation during the change process (Westlander, 1999). Participatory action research (PAR) is a form of action research that is characterized by researchers and practitioners in collaboration identifying problems, identifying reasons for problems and developing solutions (Whyte, 1991).

The overall research project aims to result in changes in practice as well as to establish new knowledge (see Figure 1.3). With the overall approach for the project declared, the author would like to point out that the research presented in this thesis will serve as a base for the change that is planned in the second part of the overall research project.

3.2 Design Research Methodology

Blessing (2008) states that design research includes development of theories and models but also development of support to get from the existing situation to the desired situation. The outline of the overall research project is based on the Design Research Methodology, proposed by Blessing et al (1995). The methodology involves different stages (see Figure 3.1), however it should not be considered as a purely sequential methodology since some stages may have to be conducted in parallel and iterations will be included (Blessing, 2002):

- By formulating *Criteria* for evaluation of outcomes from the intended research (i.e. the design method or tool) the researcher identifies what to focus on;
- In the *Descriptive Study I* understanding of the researched situation is enhanced, which will form a base for the development of the method or tool;
- The aim of the *Prescriptive Study* is to develop and propose a method or tool based on results of Descriptive Study I along with existing theories and experiences;
- In the final stage, *Descriptive Study II,* the method or tool will be applied in practice in order to evaluate whether the developed support is addressing the intended need.

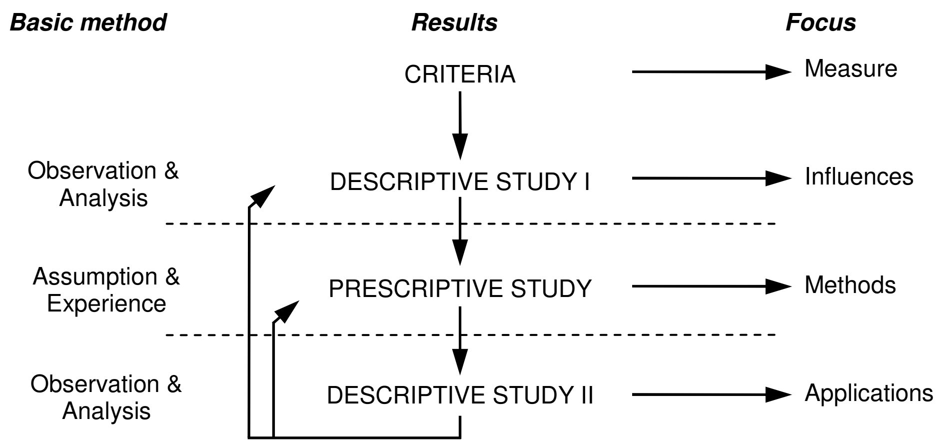

Figure 3.1: The Design Research Methodology framework (after Blessing, 2002)

The research presented in this thesis is mainly performed in the Descriptive Study I (including studies Case Study and Comparison Study) but also covers an initial step of the Prescriptive Study (Development Study). Literature studies are performed in parallel throughout the whole project. Below, the methodology used in different stages of this specific research project is presented in relation to the stages of the Design Research Methodology.

Criteria

The overall research project has the purpose to improve the concept decision process and this is expected to contribute, on a long-term basis, to more innovative products launched on the market and less rework within the development projects. However, within the research project the evaluation will primarily focus on how co-workers receive and comprehend the developed supporting method. It will be evaluated by whether the co-workers think their awareness and understanding of the decision-making situation and the consequences of the decisions are improved. Experienced co-workers will be consulted in judging if utilisation of the developed supporting method will contribute to better decisions and thereby free more time for working on innovative solutions instead of spending time and money on rework in later project phases.

Descriptive Study I

With regard to the research project, this stage aims to gain understanding of what is characterising the concept decision making. A qualitative approach has been used in this stage, since a qualitative research approach is useful when the aim is to explore an area of interest and to obtain an overview of a complex area (Robson, 2002). Two empirical studies, Case Study and Comparison Study, have been conducted as a part of the Descriptive Study I. The studies were designed to explore and describe the concept decision-making process from two separate view points (different companies at separate occasions).

Case Study

The Case Study investigated a retrospective case study where a technical concept had to be reworked later in the development project. The case study form was chosen since it provides an opportunity to understand the dynamics present within a single setting (Eisenhardt, 1989b) and to capture phenomena and contextual conditions (Yin, 1994). The purpose of the Case Study was to map what happened in order to gain more understanding of what went wrong in this specific case and to identify the factors that influenced the concept decision making process. A case should be selected carefully (Eisenhardt and Graebner, 2007) and the chosen case was considered to be interesting from the research perspective but also a learning opportunity for the company.

A case study involves empirical investigations of a particular phenomenon within its real life context using multiple sources of evidence (Robson, 2002). The data collection was mainly based on in depth-interviews, supported by document research, where internal documents such as design reviews and gate reports were reviewed. In addition, personal experience was drawn from the author's work on projects at the company and, to some extent, previous knowledge of the output from the case being investigated.

The interviews were designed as qualitative research interviews where questions were used to obtain the interviewees' opinions and experiences regarding concept decisions as well as their roles in the decision-making process. The semi-structured interview form was used, allowing the researcher to modify the order and exact wording of the pre-determined questions during the interviews, if that seemed appropriate to improve the quality of the interview (Robson, 2002). The interviews started with questions about the respondent's professional background, professional role and experience in the company. The questions continued regarding the main focus: to investigate the specific case. Respondents were given the task to report their picture of activities, roles, prerequisites, basic data and supporting methods used in the case. The respondents were also given the opportunity to reflect on the subject and to add extra comments if they felt something relevant had not been covered by the interview questions.

Respondents were chosen to represent both project and functional side of the organisation. In the Case Study technical project managers, functional managers, product attribute specialists and computational engineers were interviewed (nine respondents). The interviews were audio-recorded and transcribed word for word by the author to serve as a base for the analysis of the gathered empirical data. The author analysed the transcribed interview materials using coding and categorisation, thus beginning by identifying themes emerging from the raw data (Kvale, 1997). Parallel analysis of the data was performed by other researchers (i.e. the co-authors of the appended papers) in order to verify the author's conclusions. Based on the collected empirical data a chronological picture was created, showing the course of events of the case, which served as a support when analysing the material. The respondents participated in a verification session where some additional data and comments were added. For more information regarding the Case Study, please see Paper A and Paper B.

Comparison study

The purpose of Comparison Study was to widen the empirical base on how concept decisions are managed in practice. The Comparison Study was conducted in a company not involved in the Case Study in order to be able to compare the findings. This company's product development projects are initiated through a bidding-quotation process and customers are often cities, regions or government, in contrast to the company in the Case Study, which sells their product directly to individual customers.

In the Comparison Study technical project managers, functional managers and system responsible were interviewed (six respondents). Materials such as organisation charts and product development process overview were also provided to the researchers. The interviews conducted in Comparison Study were designed in the same way as the Case Study interviews, as semi-structured qualitative research interviews. The interview guide was developed based on the one used in the Case Study: starting with questions regarding the respondent's professional role and experience in the company. In addition, respondents were asked to report on how concept solutions were selected in the company, including activities performed, available prerequisites and supporting methods. Respondents were then asked what they regarded as the biggest challenges and problems in selecting concept solutions. Finally, respondents were able to make reflections and add extra comments if they wanted to. Analysis of the empirical data, based on the audio-recorded interviews and transcriptions, were also performed in the same way as in the Case Study. More details regarding the Comparison Study can be found in Paper B.

Prescriptive Study

The research presented in this thesis includes an initial step (the Development Study) of the Prescriptive Study, which is underway but far from finalised. Further on in the Prescriptive Study, a supporting method (taking care of results from the Descriptive Study I) will be developed incorporating research literature and best practice on concept selection. The development of the supporting method will also be based on research on change and implementation of new methods and tools in product development (e.g. Beskow and Ritzén, 2000).

Development Study

The Development Study was an interview study with the purpose to investigate what respondents thought should be improved in the concept decision-making process and also means for improvement. Another purpose was to gather more empirical data on how concept decisions are actually made in practice. It was chosen to do this interview study in the same company that the Case Study was conducted, although the Development Study was performed two years later and were not only focusing on a specific case.

The interviews performed were designed as semi-structured interviews, just as in Case Study and in Comparison Study. The main questions during the interviews regarded how concept decisions are made in practice today, how it *should* be done (according to internal instructions), what ought to be improved, and what is needed to make improvements happen. In total 33 respondents participated, again chosen to represent different roles, departments and hierarchical levels. From the interviews each statement addressing the main questions was transcribed. Further, the statements were categorised and coded according to the emerging themes (Kvale, 1997). See Paper C for more details regarding the Development Study.

Descriptive Study II

This stage has not yet been performed. During the second part of the overall research project it is planned to include testing of the proposed supporting method in practice, and to evaluate it according to the Criteria specified earlier.

Relationship between conducted empirical studies and appended papers

This thesis presents results based on three empirical studies (Case, Comparison and Development). Paper A presents results from the Case Study. Paper B is based on a comparison between the results of the Case and Comparison Studies. Finally, results from the Development Study are provided in Paper C. The relationship between the empirical studies, appended papers and their positioning in the overall Design Research Methodology is visualised in Figure 3.2.

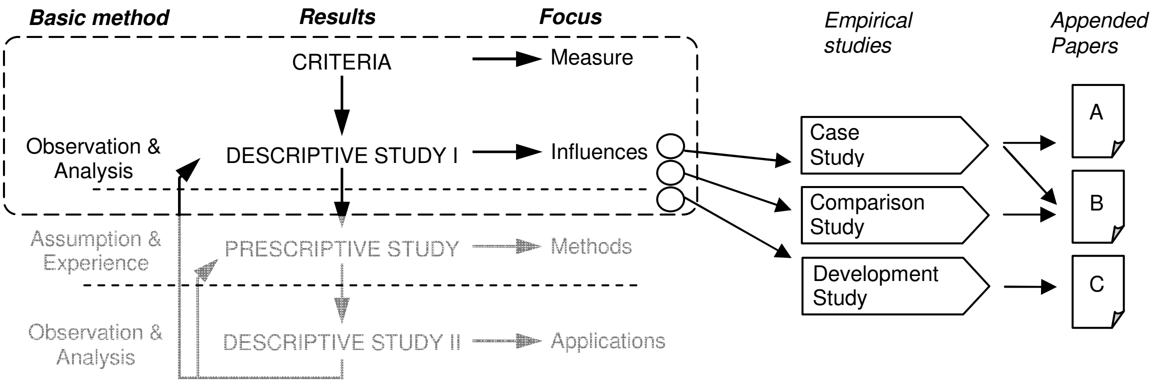

Figure 3.2: The research presented in the thesis (empirical studies and appended papers) positioned in the Design Research Methodology

4 Summary of Appended Papers

The appended papers (Paper A, B and C) are here presented in a summarised form in order to clarify the contribution from each paper to the discussion and conclusions. For more in-depth detail, the reader is directed to the appended papers.

4.1 Paper A: Challenges in Concept Decisions in Complex Product Development

Purpose: To explore a retrospective case in one company in order to identify what influencing factors were present in the concept decision-making process. The specific case was chosen because it had to undergo severe rework in later development phases and was therefore considered to be an interesting study object both for researchers and company.

Main findings: The investigated case, the concept decision process of a subsystem in a product, did run across several obstacles on the way to the launch of the product. The investigated case had suffered due to too many changes were going on in the organisation at the time, resulting in the concept development and the technical concept issues not receiving the attention they required. For example a re-organisation of the R&D division meant that the technical issues lost some focus in the start-up of the project in favour of more organisational issues. Furthermore, many comprehensive changes appeared after the concept phase was finished. Those late changes of prerequisites (e.g. new exterior styling) contributed to the solution becoming degraded when compared to the new prerequisites.

Several decisions and activities were found to influence the concept decision process, directly or indirectly, through e.g. changed, erroneous or late information. It was concluded that both formal and informal factors influenced the concept decision in the case. The list of influencing factors identified included: *Project and product request, Supporting structures and routines, Individual competence and driving forces, Teamwork and company culture* and *Contextual circumstances*. This initial list of factors helps to point out what areas can be subjects for further change efforts. The main influencing factors represent different perspectives and on what level they have influence: the *individual* (dependent on the individual's goals, competence etc.), the *team* (interaction between individuals), the *project* (the performance of the specific project), the *organisation* (the prevailing structure and formal processes in the company, which is not project specific) or the *context* (the events in the surrounding world). The range of perspectives highlights the fact that all five levels have to be taken care of when defining proposals for improving the concept decision-making process. This forms a base for discussions on further change work, and proposals for improvement should therefore have different characteristics and correspond to the different perspectives.

Authors: Kihlander, I, Janhager, J and Ritzén, S

Distribution of work: Kihlander, Janhager and Ritzén had a close collaboration in all parts of the study. Kihlander had the main responsibility for the data collection, where Janhager supported Kihlander during the first interviews, and the writing.

4.2 Paper B: Deficiencies in Management of the Concept Development Process: Theory and Practice

Purpose: To identify and discuss deficiencies in both theoretical models and industrial product development regarding concept decision making, based on interviews in two industrial companies (Alfa and Beta). An additional purpose was to supplement previous research on understanding how concept decisions are made in practice.

Main findings: Respondents reported that minor decisions, maybe not labelled as a decisions that mattered for the concept decision at the time, were made (some times ad hoc) along the way during the development. The respondents could not separate the decisions from the concept development performed, and therefore concept decisions were hard to identify explicitly due to the fact that they were found to be embedded in regular development work.

In both investigated companies it could be reported that both formal and informal factors did influence decisions made during the development. For example, in company Beta respondent came back to the cultural issue time after time (their culture contra the customer's culture). *The development team faced the challenge to interpret how the customer interprets* the contract since their customer of the project is present during the development, and they had experiences of earlier misunderstandings in the communication with the customer. The study clearly shows that it is not only formal factors that influenced, confirming earlier findings.

In the investigated case in Alfa it was reported that the solution got too detailed too early, and alternatives were not evaluated. Neither of the two studied companies was following the in literature proposed 'generate, evaluate and select' process or using concept evaluation methods recommended in theory. Instead they rather spent the time struggling to develop *one* solution that was good enough to meet the requirements and specifications. Therefore it was more of accepting deviations (prioritise, and trade-off) than choosing between alternative solutions. The compromising and prioritising are not shown distinctively in the academic models, even if it is often mentioned in the detailed descriptions in the textbooks.

Both investigated companies do have internally defined formal working procedures that prescribe how product development is to be carried out within the company. In the interviews the respondents in the two companies often referred to the internal formal working procedure. Therefore, when discussing the gap between theory and practice, which has been done before by other researchers, the companies' internal working procedures also have to be considered. When defining actions for change, one has to consider the gap - not only between the theory and practice, but also between the theory and formal working procedures in the company, and between the formal working procedures and the practice.

This has implications for companies' internal product development processes. The methods should be modelled to really support the operations – not just showing idealistic and simplified models. The findings show that the transition from academic theory into formal working procedures within a company includes a risk that that theoretical models are not used to their full extent. In the same way, engineering design literature should be challenged: the ways to visualise and communicate the complexity of their product development models should be improved.

Authors: Kihlander, I and Ritzén, S.

Distribution of work: Kihlander performed the planning, conducted the interviews and made the analysis. Ritzén was involved in the analysis and writing.

4.3 Paper C: Concept Decisions – a web of interconnected actions

Purpose: To explore the understanding of concept development and to discuss potential improvements and means for future implementation of the improvements based on an interview study in one company.

Main findings: The respondents agreed with the academic definitions that a *concept* is a rough solution, but in further discussions it emerged that the word *concept* was used with different meanings depending on what part of the organisation a respondent represented. Furthermore, about a third of the respondents also associated the word *concept* to the *concept phase*, and more of the state of mind used when investigating solutions on a higher abstraction level. Hence, the understanding of concept in literature should be complemented to show that *concept* can also be a state of mind.

A major result from the in-depth interviews was that concept decisions are not made at a certain point in time, instead *a concept decision is a web of interconnected actions with many activities integrated and embedded in the process*. The decision process was perceived as more structured than it had been before, mostly due to implementation of a sign-off process and usage of templates presenting alternatives in the system selection process, which resulted in alternatives being generated and evaluated. The usage of template for system selection was referred to by a majority of the respondents, at both managerial and engineering level.

A challenge in comparing alternatives (maybe having different maturity levels), can be "to get past" the reference solution, which can be a well known solution that is used in products are already available in the market. Another challenge in these early development phases is that each system undergoing early development should function together with all the surrounding systems, who probably also are under development. This may result in compatibility problems and was highlighted by several respondents to be one of the biggest issues to take care of when improving the concept decision-making process. When analysing solution alternatives the respondents reported that they were not guided by the organisation regarding what evaluations criteria to use. Instead, the system experts made their own prioritisations, according to what they thought the brand stood for. However, the respondents also commented that discussions regarding evaluation criteria and their weighting were more important than the exact form of the weighting functions.

Something applicable to managerial roles, but also concept engineers, working in concept development is that they should be able to work under uncertain conditions. When discussing improvement proposals a strong wish from several respondents was to have more concept engineers who are capable of developing new technical solutions, based on extensive experiences without getting stuck in details, and who are able to work well under uncertain conditions. The difference in managing early phases and later phases of product development was also discussed extensively by the respondents. It is important, in these early phases, to have an open climate that signals that it is acceptable to make mistakes. Therefore, the management should reward successes, but also appraise setbacks in a positive light, so that only inactivity is penalised.

Based on the analysis of the interviews it is stated that there are two main areas that should be addressed as a means for improving the concept decision-making process. The first on is developing *mindset* meaning the required mindset in management of the concept development and the second one is applying *methods* meaning that certain methods and document were found to effect the process (e.g. templates for system selection but also the role description for the people who do the actual development work).

Authors: Kihlander, I and Ritzén S.

Distribution of work: Kihlander and Ritzén planned the study together. Kihlander performed the empirical data gathering, analysis and writing.

5 Discussion

In this chapter the research findings from the empirical studies are discussed in relation to existing theories on concept development and decision making. The first sections aim to give a background and contribute to the understanding through discussions of how the word *concept* was used by the respondents, and what was found to characterise and influence the concept decision-making process. Additionally, a discussion regarding the internal formal working procedures within firms is also presented. In the following section pragmatic means for improving the concept decision-making process are discussed. Finally, the research questions are revisited, together with a discussion on the research approach and methodology. The appended papers will be referred to as Paper A, B and C in the discussions below (Paper A: *Challenges in Concept Decisions in Complex Product Development*; Paper B: *Deficiencies in Management of the Concept Development Process: Theory and Practice*; and Paper C: *Concept Decisions – a Web of Interconnected Actions*).

5.1 The use of the word concept

To begin with, the common usage of the word *concept* has to be elaborated since the author made some interesting observations during the interviews: both similarities and differences were found in how respondents defined the word *concept*.

The similarities were that respondents would agree to the definition of a *concept* as an approximate description or an idea (Ullman, 1997; Ulrich and Eppinger, 2008). Also, the respondents, all employed in product development organisations, discussed the idea and technology *in* a concept rather than following the reasoning that concepts should include both *the idea with* (need/market) and *the idea in* a concept (design/realisation) (according to Hansen and Andreasen, 2002).

However, when deepening the discussions to capture the respondents' understanding of *concept* and *concept development* (Paper C) it was discovered that the word *concept* was used with different meanings within the investigated organisation (also observed in earlier research by Setterberg, 2008). Depending on what part of the organisation the respondent represented, the word *concept* was used in the sense of a solution on the product level, or describing a solution on the system level (referring to a hierarchical product structure: product, system, subsystem and component levels). Any negative consequences due to the different uses of the *concept*-word could not be observed in the empirical studies. The author's reflection is that the development personnel gather around the 'real' products to be developed, using the real names on e.g. the systems, and therefore the exact meaning of the *concept*-word becomes less important in their everyday work. In spite of the discrepancy in the level of a *concept* (product or system level) the author claims that the challenges for managers and co-workers are very similar: essentially choosing what solution to pursue (maybe having alternatives - possibly with different maturity levels), based on incomplete information. Therefore, the author suggests that the discussion provided here addresses both situations in a proper way.

In addition, in the interview study presented in Paper C, about a third of the respondents associated the word *concept* also to the activities they performed in the *concept phase* and the attitude they had to these activities. The respondents commented that: *"…it is before it is in* *place…"*, *"…you familiarise yourself to the technical content …"* and *"… you choose before you know…"*. This means that the solutions do not have to be ready, whilst the people must be confident and ready to answer despite the incomplete information that is available in early product development phases. Therefore, the author concludes that the respondents have a specific state of mind when investigating solutions on a higher abstraction level. Upon finding no correspondence in literature, the author would like to enlarge the understanding of how the word *concept.*

5.2 Characteristics of the concept decision-making process

In the empirical studies (reported in Papers A, B and C) the researchers tried to capture how concept decisions are actually made and it was possible to identify a number of characteristics of the concept decision-making process. The findings are also compared to what the literature states in each matter.

The work with concept development was reported as working with rough solutions, involving many open ends. The activities are overall characterised by uncertainty and ambiguity, due to the fact that there are no answers, only questions. Everything - such as targets, solutions, competitors, legislation, and planning - is changing and the people working within concept development have to be prepared that anything can happen, and that everything can change. They are 'prepared' in the sense of having the 'concept state of mind' that was identified in the empirical studies as specific to concept development. Hence, they experience *The Design Process Paradox* (Ullman, 1997) for real.

Several product systems developed in parallel

Complex products (such as the products developed by the investigated companies) include many product systems and several technologies resulting in many product system interfaces to handle during the development. It is then a challenge to meet all initial requirements in every attribute and every product system. Another challenge is that the ingoing product systems are under development simultaneously, which can create some uncertainty in the interfaces. One respondent commented that: "*…the pitfall might not be the technical challenge within each system but rather the problem of having a large number of issues that should be treated at the same time…*". Another respondent concluded: "*…it is very complicated; there are many things that should fall into place at the same time…*". Therefore, any proposals for improvement should support the decision maker in handling interfaces with adjacent product systems.

The difficulty of having alternatives to evaluate

Within each product system solutions are developed. In Paper A and Paper B it was reported that most of the respondents' time was spent on developing one solution within the specific product system, and that alternatives were actually never generated and evaluated (which can be added to earlier observations of such behaviour, e.g. Blessing, 1994). For instance, a respondent reported that they were not looking for the optimal solution: due to the prerequisites and available time, the product developers instead spent the time struggling to find *a* solution (as in *any*), that was good enough to comply with the requirements.

Benefits of having alternatives when making decision have been asserted in earlier research (e.g. Eisenhardt, 1989a; Nutt 1999) and the concept evaluation methods prescribed in engineering design literature assume that there are concept alternatives to choose from (e.g. Pugh, 1990; Ulrich and Eppinger, 2008). However, as seen in the empirical studies reported in Paper A and Paper B, alternatives are not always generated and reasons for that can be many. During the interviews some respondents elaborated on the need for alternatives versus the available time to develop them. Not developing alternative solutions could be due to designers and decision makers getting stuck on a specific alternative, which can be seen in Paper A. There are a number of reasons why a person is unable to see other alternatives, or to evaluate them in an objective way, e.g. fixation or anchoring to a specific solution (e.g. Jansson and Smith, 1991; Hammond et al., 1998; Gilovich et al, 2002; Cross, 2006). The effect of fixation and attachment to a specific solution can also be related to respondents' reporting problems "getting past" the reference solution (often a well known technical solution used in products that are already available in the market, which means that it is developed and verified in detail).

Having alternatives to choose from is recommended in literature, but is hard to achieve in practice, according to the empirical results presented here. Therefore, the author concludes that a challenge in defining improvements for the concept decision-making process is to find a way to encourage alternatives to be developed, and to compare them despite their different maturity level.

Support for evaluation of alternative solutions – when having alternatives

An interesting reflection made by the respondents, reported in Paper C, was that the process of choosing concept solutions on the system level had become more structured during recent years This represents a transition from what was initially reported in Paper A (from studies in the same company two years earlier) where only one solution was developed within the studied product system. The transition had two main reasons, according to the respondents. First - implementation of a sign-off process, used to cascade the requirements from the complete product level to the engineering departments that develop the system solutions. The sign-off process includes confirmations of both understanding and meeting the requirements, and engages different roles in the organisation. Second - implementation of a template for system selection, showing alternative solutions on the system level, encouraging the development of alternative solutions.

In general evaluation methods were not often reported to be in use, except on the occasions when the system selection template was used. However, there were some exceptions: some respondents gave account of evaluating solutions not related to the system selection process. They reported that in these cases they used a simple matrix in Excel that they designed themselves (Paper C). To use a matrix structure is suggested by many authors (e.g. Pugh, 1990; Roozenburg and Eekels, 1995; Ulrich and Eppinger, 2008), but none of these specific methods were reported as used by the respondents, nor were any analytical methods observed, for example the Analytical Hierarchy Process (recommended by Saaty, 1990) or the Analytical Network Process (recommended Ayag and Özdemir, 2009).

The template for system selection referred to in Paper C is an Excel template into which the system expert (responsible for the product system) is required to feed information. First, the alternatives are listed; then a number of criteria are listed; and finally the values of each solution against each criterion are filled in. The evaluation criteria were not provided by the organisation (i.e. the management), but were instead defined by each system expert, based on their own prioritisations and according to their picture of the brand identity. In the template for system selection there is a weighting function for the evaluation criteria, i.e. an opportunity the rank criteria and give them relative weights. It was reported that some of the system experts used the weighting function, whilst others did not. Some of them commented that they did not understand the weighting function and some that they had not seen the point in using it. Furthermore, some of the system experts commented that they had tried to use it, but stopped when they did not see it as adding value. It has been noted before that limited time is spent on the aspect of criteria importance (Girod et al, 2003).

Finally, a majority of the respondents commented that, even if they use a template with weighted criteria, they do not want to rely only on figures in the template, preferring to be able to add their own personal reflections, using their experience and intuition in the decisions (Paper C). The importance of using the more intuitive side has been pointed out earlier (e.g. Patton, 2003; Zeelenberg et al, 2008). The respondents also commented on the value of discussion when using the evaluation template (Paper C). The exact form of the criteria weighting function was considered to be less important than the fact that the discussion took place at all (Paper C), which correspond to earlier findings regarding values of using structured supporting methods (e.g. Norell, 1992; Wright, 1998).

Therefore, it can be concluded that it is important that a template for evaluation of alternatives triggers discussion, since these were considered as very valuable by the respondents. In addition, it was found in the investigated company that understanding of the brand values indirectly affected which evaluation criteria were defined. Thus the vision of the brand must be well communicated and agreed upon throughout the company.

Compromising and handling deviations

As commented above it was reported in both Paper A and Paper B that the development teams primarily worked on one solution within their specific product system. Instead of comparing alternatives, they spent a lot of time compromising on the one solution that they focused on (Paper B). If the development team discovered that the solution might not meet the target with regards to a specific attribute, a process would then be initiated to find out whether a deviation from the initial target could be worth considering. Consequently, in a complex product including many interfaces, there may be a large number of compromises and deviations to handle.

Furthermore, both investigated companies spent much time on reusing solutions from previous projects, both to save money (e.g. tooling investments) but also to fall back on known solutions (e.g. for robustness). The reusing of solutions adds restrictions to the development process, as there are many interfaces in the product that are frozen from the beginning.

To conclude, product development work, as reported in Paper A and Paper B, is largely about reusing, but also revolves more around compromising and accepting deviations (prioritise, and trade-off) from the original wish lists for each product system than on choosing between alternative solutions. The author does not find this discussed correspondingly in the prescriptive engineering design literature, which instead presents more idealistic models of product development processes. Therefore the author questions whether the prescriptive engineering literature uses overly idealistic models, and asks whether the literature can support development teams in planning and coordinating their activities in a way other than giving an overview?

The findings cannot be explained by rational decision making theories

When comparing the findings from the empirical studies to classical rational decisions theories, it can be stated that there is a weak resemblance between the two. Stable preferences, a requirement for rational decision making (according to March, 1997), are hard to apply when comparing different concept alternatives with different maturity levels (Paper C), or when the final requirement specification is not provided at the time of the concept evaluation (Paper A). It has also been found, in earlier engineering design research, that designers tend to forget previously identified criteria, and that criteria can evolve during the process (Dwarakanath and Wallace, 1995). Additionally, the respondents in the empirical studies reported that the search for solutions ended when they found a solution that was good enough, which is not in accordance with the rational decision-making theories (Paper B). Based on the findings from the empirical studies, it can be stated that rational decision-making theories are not applicable to describe or to explain concept decision-making process in the studied industrial settings. Instead this bears more resemblance to contingent, or adaptive, decision making (Payne, 1982; Bettman et al, 1998), where the decision maker decides what preferences to use in each specific decision situation. Consequently, when proposals for improvement are defined, the author concludes that one has to be careful when regarding which decision-making theories will be used, and not take for granted that people act rational in decision making.

Actors on different organisational levels

During the interviews none of the respondents could give an account of the total concept decision-making process (Paper A, B and C). Instead each person accounted for their part of the process, giving different perspectives, explaining different activities. The main process that emerged from the interviews was the following: It starts with individuals, the system experts, who have deep knowledge of the product system and should be updated on what requirements the future product should comply with. The system expert decides what alternatives to develop, taking in influences from the environment, and often the development is performed as a team effort within the organisation. The system expert documents the alternatives in a specific system selection template, and selects what to recommend for the specific project. Finally, the recommended solution enters into the project, meaning that the organisation decides exactly which solution will be implemented in the project, based on the recommendation of the system expert.

Study of this process shows that there are many actors that participate, acting on different levels, which complements the findings of Hansen and Andreasen (2004). The process that emerged from the empirical data (Paper C) resembled, to a certain extent, the theoretical model on decision-making process in the Fuzzy Front End of discontinuous innovation presented by Reid and de Brentani (2004). Developing cars might not be considered as discontinuous innovation according to the nomenclature of Garcia and Calatone (2002), since cars have been on the market for about hundred years. However, the systems within car products may be used as examples of just that. When investigating the decision-making process at the company (where the system experts do a job preceding the actual development projects) Reid and de Brentani's (2004) process helps to elucidate important interfaces where information flows in the decision-making process. The knowledge of these interfaces will help when defining improvements for the concept decision-making process.

Since the concept decision-making process is found to involve multiple actors in different roles, and on different organisational levels, it is concluded that supporting working procedures have to support the information flow through the interfaces between these levels.

Web of interconnected activities

As a result of the analysis it was stated that concept decisions were hard to demarcate exactly, and it was also found that concept decisions are not made at a certain point in time. Instead many major and minor decisions and activities add up to the decisions in the product development projects in the investigated organisations (Paper A, B and C), confirming earlier findings of both implicit and tentative decisions in product development (Hansen and Andreasen, 2004; Lopéz-Mesa and Chakrabarti, 2007).

Why the concept decision-making process is hard to capture may have many causes. For example concept development is found to cover more than is traditionally included in the concept stage within the structured product development process i.e. the stage gate process in the company (Backman et al, 2007). Another reason, according to the author, may be that every individual is *a* player in the total process, and maybe it is too complicated for a person in the organisation to capture the total concept decision-making process since each person only controls or participates in a small portion of the total process. It is also worth mentioning that when conducting the interviews, some respondents commented that this was the first time they had ever reflected on the decision-making process in the organisation.

To summarise the findings on how concept decision are made (many activities, many actors, and several levels), it can be concluded that the concept decision-making process is found to be *a web of interconnected activities, with many decisions integrated and embedded in the process of the regular development work*.

5.3 Factors found to influence concept decisions

The purpose of this section is to describe what was found to influence concept decisions. Based on Paper A and Paper B it was concluded that both formal and informal factors have influence (formal factors can be supported by routines and procedures, whilst informal factors need different management approaches). The analysis of the case in Paper A left no room for doubt that more than formal factors (e.g. technical requirements) were influencing the process that resulted in which solution was chosen. Based on the case in Paper A five main influencing factors were identified: *Project and product request, Supporting structures and routines, Individual competence and driving forces, Teamwork and company culture* and *Contextual circumstances* (see Table 5.1). Examples of sub factors are also given in the table, for example *Skills for screening information*: in large organisations the management hierarchy is exposed to a massive information flow. Individuals have to be able to listen to everything, extract the essentials and judge what information should be reported further up in the hierarchy.

Table 5.1: Main influencing factors, examples of sub factors and their influencing levels

Main factors	***Examples of sub factors***	***Formal/ informal***	***Influencing levels***	***Characteristics***
Project and product request	▪ Product requirements ▪ Project connections	Formal	Project	Project specific, new set up for each project
Supporting structures and routines	▪ Area of responsibility ▪ Procedure for reporting	Formal	Organisation /company	Not project specific, valid for all projects in the organisation
Individual competence and driving forces	▪ Skills for screening information ▪ Technical knowledge	Informal	Individual	Personal, specific for each person
Team work and company culture	▪ Company culture ▪ Working climate	Informal	Team	Between individuals
Contextual circumstances	▪ Robustness in the organisation ▪ Market changes	Informal	Environment	The environment, the surrounding world

The main influencing factors represent different levels of perspective, meaning on what level they have influence: the *individual* (dependent on the individual's goals, competence etc.), the *team* (interaction between individuals), the *project* (the performance of the specific project), the *organisation* (the prevailing structure and formal processes in the company, which is not project specific) or the *context* (the events in the surrounding world) (also listed in the Table 5.1). The different levels of perspective are connected to each other and a visualisation of the relationships can be found in figure 5.2. The individuals and the team are making the decisions, and each individual is a member of a team. The team then performs its tasks within a project, the project is performed within an organisation and finally the organisation operates in the environment. The different levels of perspective highlight that all five levels of perspective have to be considered, each having different characteristics, when defining proposals for improving the concept decision-making process.

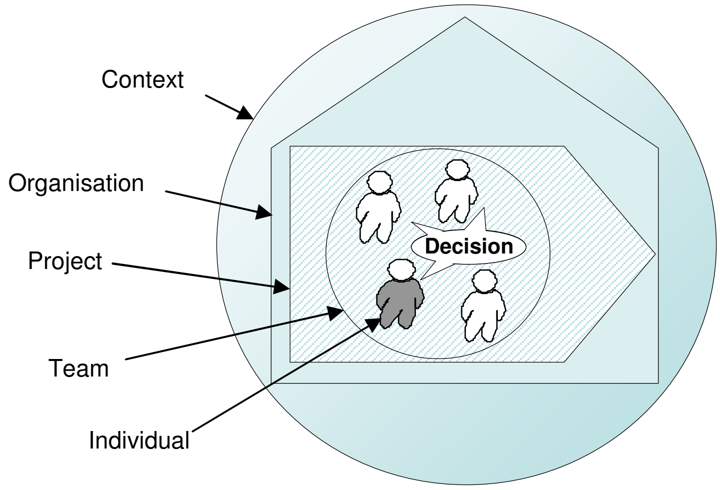

Figure 5.1: Different perspectives of the influencing factors

A result from Paper B was that the role of internal formal working procedures within companies was observed as being important. The author suggests that internal working procedures (defined within the companies) have not been discussed earlier in engineering design research and has therefore chosen to discuss it in more detail in the following section. The internal formal working procedures act on the organisation level (referring to Table 5.1 and Figure 5.1), meaning that they are defined within a company, and are valid for the whole company i.e. not specific for each project. Other examples of sub factors on the same level are role descriptions and organisational charts.

5.4 Internal formal working procedures

The concept decision as a web of interconnected activities found in the empirical studies bears no resemblance to what is proposed in the prescriptive engineering design literature, i.e. the product development process as a stepwise progress in a structured way: generate, evaluate and select (e.g. Roozenburg and Eekels, 1995; Ulrich and Eppinger, 2008). Nor does it reflect what the companies own prescriptive models present. The difference between the prescriptive rational step-wise processes and models and the investigated practice has been observed before (e.g. Blessing, 1994; Suwa et al, 2000; Stempfle and Badke-Schaub, 2002), and the findings here serve not only to confirm that gap, but also to enlarge the discussion.

The findings also confirm the low rates of utilisation of supporting methods reported in earlier research (Araujo and Benedetto-Neto, 1996; Janhager et al, 2002; Salonen and Perttula, 2005). The low utilisation may have many causes. The methods may not fulfil the needs of the product development practice and are therefore disregarded. Organisations may nurture habits that hamper utilisation, such as a stressful climate where supporting methods are seen as a hindrance in practice; i.e. there is a major difference between having methods available in the company and being able to use those methods. Additionally, the practitioners might use a method without knowing the exact name or originator of the method (i.e. the theoretical reference, which is naturally used by academics) and therefore report that they are not using any methods.

Companies such as the two investigated here do have supporting structures and formal supporting working procedures, such as process instructions and role descriptions. An internal working procedure may be derived from an academic origin, but the reference may be lost along the way and now the internal working procedure stands for itself, with only weak resemblance to the academic original (Paper B). This might be another reason why the methods are not called by their official name.

The gap between theory and practice has been mentioned in earlier research (e.g. Hansen and Andreasen, 2004) but based on the findings in the empirical studies, the author claims, that there are actually three entities to consider (Paper B): the prescriptive academic theory; the internal formal working procedures within a company; and the practice carried out by practitioners (Figure 5.2). Hence, there is not only a gap between theory and practice (which has been stated before) but also a gap between academic theory and internal formal working procedures, and a further gap between internal formal working procedures and the practice. The formalised working procedures (a third entity) needs to be highlighted in the discussion regarding the gap between theory and practice since the internal formal working procedure is found to play a more important role for the practitioners than the academic theory. Therefore the role of internal formal working procedures has to be included when planning change actions (Paper B).

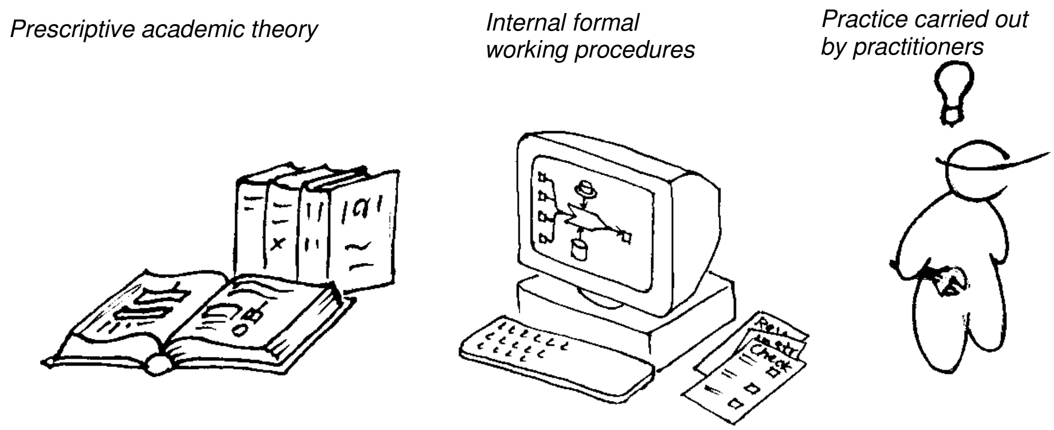

Figure 5.2: The theory, the practice and the formal procedures in between

As an example the iterations in the development process can be mentioned. It was noted in the Theoretical Framework chapter that iterations in the process are often mentioned in the detailed presentations of a product development process in the engineering design textbooks, but not in the overview pictures (e.g. Ulrich and Eppinger, 2008). Correspondingly, in the companies' models there are no iterations illustrated, nor are they planned for in the industrial projects.

The findings show that the transition from the prescriptive academic theory into internal formal working procedures within a company includes a risk. The theoretical models may not be used to their full extent, and some key functions may be lost if the internal models are made too idealistic, using only the overview pictures in the textbooks and not scrutinising all detailed comments in the textbooks e.g. on iterations (Paper B). The challenge within a company is then to define internal formal working procedure in a way that really supports the organisation and the engineering practice, complementing the already existing overview models. Therefore, the author would like to challenge companies to be more aware of the implications and the role of the internal formal procedures, and of how the formal internal working procedures are developed. Additionally, the engineering design literature has to be improved to visualise and communicate the complexity. Currently the complexity is mentioned, but the theoretical models are not communicating it clearly enough.

To conclude the discussion on companies internal formal working procedures, the author wants to emphasise that there are three entities that have to be addressed in three different ways; *theory*, *formal working procedures* and *practice*. The author claims that companies' internal working procedures have been insufficiently discussed in previous engineering design research.

5.5 Means for improving the concept decision-making process

The previous discussions in this chapter aimed to contribute to a deeper understanding of concept decision making in industrial practice, based on studies manly in one focused industrial company, complemented with an additional study in another company. This section will be more directed to the future, discussing pragmatic means for improving the concept decision-making process defined from the analysis of the empirical studies and available literature.

In Paper C it was reported that respondents had a number of issues they wanted to improve in the concept decision-making process. For example they mentioned having problems when comparing different solution alternatives with different maturity levels; problems with compatibility between different product systems that were developed in parallel; and they called for a certain management attitude in the concept work. The purpose of the interview study reported in Paper C was to discuss what the respondents considered as a means for improving the concept decision-making process. Based on analysis of the interviews it was concluded that two main areas should be addressed as a means for improving the concept decision-making process - namely developing the mindset of management involved in concept development and applying supporting methods available for use. These two areas can be related to earlier findings presented in this thesis regarding on what levels the concept decision-making process is influenced (Figure 5.1). How management acts refers to the *individual* and *team* levels, and the supporting methods refers to the *organisation* level.

Additionally, recommendations complementing the discussion will also be suggested by the author, based on the research presented in this thesis in combination with earlier research findings (prescriptive methods as well as critique given in descriptive studies). The recommendations are intended to be valuable for those who will manage the concept decision-making process, but also for those who will design and plan improvements of the concept decision-making process.

Mindset in concept decision making

The respondents discussed extensively (in Paper C) that a certain kind of mindset is required in conceptual phases (e.g. working with uncertainty), addressing managerial roles, but also co-workers. The mindset should support working in concept development, meaning accepting the fuzziness that is omnipresent, not getting too detailed too early, daring to make mistakes, and allowing other people to make mistakes (Paper C). Many respondents wanted more concept engineers, meaning engineers who are able to work under uncertain conditions, have deep technical competence and are not afraid of doing the CAD-work. Consequently, different management approaches are needed in early development phases than in later development phases. The need for open climate in innovation environments has been asserted earlier (Ekvall, 1996; van Riel et al, 2004; Menzel et al, 2007). Therefore management should reward action (both successes and failures), only penalising inaction (Paper C). Ekvall (1996) strengthens the respondents' view of management's role claiming that the climate is, to a fairly large extent, in the hands of the manager.

Paper A reported on a re-organisation and the results showed that restructuring could result in a more fragmented organisation leading to, among other things, a reporting failure that was largely due to the less open communication climate that arose. For example, there was an awareness of important issues at lower levels of the organisational hierarchy, but this did not extend to higher management. Researchers have earlier pointed out the need of management to handle organisational barriers in order to achieve a better climate, and thereby better decision procedures (Ekvall, 1996; Nutt, 1999; Menzel et al, 2007).

It was noted during the interviews that co-workers' own understanding of the brand did indirectly affect prioritisations made when evaluating different solution alternatives, since the weighting of evaluation criteria was made individually (Paper C). Here, management should create a mindset that is striving towards the overall vision, rather than sub-optimising each system solution (addressing the compatibility issue in Paper C), since shared mental models are essential to reach a common successful decision (Badke-Schaub and Gehrlicher, 2003). This relies a great deal on management having communicated a clear picture of the vision for the brand and the company if the prioritisation in different teams is to be consistent.

One of the most powerful managerial tools, according to the respondents (Paper C) was the ability to ask questions, to "see" the people and acknowledge the effort spent. This is backed up by previous research (e.g. Nutt, 1999, Menzel et al, 2007), who assert that management should communicate with co-workers, ask them the right questions and pay attention in order to bring meaning to the work done. “Pay attention to every idea, no matter how unlikely, because today’s loser might become tomorrow’s winner” (Nicholson, 1998, p38).

In the case presented in Paper A, respondents recalled that all decisions seemed good at the time they were made, but acknowledged that, in light of later changes and new knowledge, some errors could be seen. Decision makers act on whatever information is available to them at the time, making as good decisions as possible at that moment. However, as clearly shown in Paper A, things can change and an early decision can turn out to be really bad in light of changed circumstances. This could be highly significant for early phases when concept decisions are made and should therefore be discussed openly in large organisations. Thus the author suggests that enhanced awareness and knowledge of the concept decision-making process and the influencing factors – for both management and co-workers - would improve the concept decision-making performance at a number of levels:

- Actors will be more prepared to handle challenges that will occur during the concept decision-making process. Training should be provided for managers and co-workers in discovering cause and effect in the decision processes, and encouraging continuous reflection upon working methods. Through awareness of these influencing factors (Table 5.1), and by discussing them openly, concept decisions could be made in a more conscious way (Paper A).
- Knowledge regarding what might affect the judgement of a specific concept (such as where it has its origin or how much the decision maker knows about it) would be enhanced (Reidenbach and Grimes, 1984; Backman et al, 2007).
- There would be a raised awareness of possible biases and pitfalls in decision-making in general (e.g. Hammond et al, 1998; Jansson and Smith, 1991; Gilovich et al, 2002; Cross, 2006).

To conclude, the author states that creating the right *mindset* - meaning awareness of the concept decision-making process and the right attitude for managing work in the concept development- in the organisation (through e.g. education), addressing both management and co-workers, is key in order to improve the concept decision-making process. This is a challenging task for companies, but nevertheless, it should be considered.

Supporting methods for concept decision making

In the empirical studies it was reported that supporting methods were not used to a large extent. However, when the process of concept decision making was unfolded during the analysis in Paper C, it was identified that all respondents had a common reference point in the process. Even if they reported the process from their own perspective (i.e. different hierarchical levels, referring to different activities), they all mentioned the template for system selection. The usage of the template for system selection was also observed by the author when participating in some project meetings at the time of the interviews reported in Paper C. Based on this, the author concludes that the template for system selection is used and that this template can be considered as an obligatory passage point in the concept decision-making process. This indicates that power is displaced into the template, in the same way that Christiansen and Varnes (2007) observed when studying gate meetings, meaning that the template governs what is asked for. Therefore the author conclude that the design of the documents can have a large impact in the process and the following discussion will focus on the template for system selection as a possible means for improving the concept decision-making process.

Due to the fact that roles on different hierarchical levels did refer to the same template for system selection, it can be seen as acting in the information flow interfaces between the hierarchical levels (resembling the decision-making interfaces observed by Reid and de Brentani, 2004). Therefore, the design of the template for system selection may have strong impact on the process, more than the organisation is aware of, and this puts great responsibility on the design of the template. The awareness of the displaced power of the templates is something that ought to be highlighted in managerial discussions: if a criterion is not in the template, it will not be evaluated.

In some interviews with system experts (i.e. those who actually do the concept development work), they referred to their role description and what the role description instructed regarding concept development. Therefore, the author asserts that the role description for the co-workers doing the actual development work can also be considered as a document with displaced power, alongside the template for system selection. In theory this implies that the findings of Christiansen and Varnes (2007) regarding the power displaced into the templates could be somewhat extended to say that certain role descriptions can have the same displaced power. In practice, this implies that if, for example, the compatibility issue is to be resolved it should be addressed in both the template for system selection and in certain role descriptions.

There are many available supporting methods and templates regarding concept evaluation but none of them take into account all problems that appear in practice. Below, the author has summarised an initial list of prerequisites and requirements as input for the development of a supporting template for the evaluation of alternative solutions:

- Use a matrix structure. This was used when the respondents designed templates by themselves (Paper C), and it can therefore be concluded that a matrix structure feels natural to product developers. In previous research Salonen and Perttula (2005) found that analytical methods, such as the Analytical Hierarchy Process, were too complex to use. There are several matrix methods to look at for inspiration (e.g. Pugh, 1990; Ulrich and Eppinger, 2008).
- Consider usability. The matrix should be created in a computer program that is common in the work place (Paper C). It should be easy to print, and the printed version should fit into a standard paper format.
- Ask for alternatives and ensure that they are evaluated (Paper A and Paper B), since having alternatives is known to be productive (Eisenhardt, 1989a; Nutt 1999).
- Provide a way to neutralise any differences in the maturity levels of the alternatives (Paper C).
- Ensure that the solutions are not too detailed too early, and that decisions are not made too early (Paper A), using for example the approach of Set-Based Concurrent Engineering (Ward et al, 1995; Morgan and Liker, 2006).
- Use a combination of a qualitative reason-based step and some sort of weighting of the different evaluation criteria, since the respondents did not want to depend totally on figures in boxes (Paper C). Examples of hybrids between rational and psychological methods proposed are Ahn and Dyckhoff (1997) and Ullman (2002).
    - The respondents valued the discussions that were initiated by weighting the criteria, but the author could not conclude exactly what weighting function that was preferred (Paper C).
    - The author proposes that questions regarding the rationale behind the final decision could be included in the template, addressing the traceability issue highlighted by Ng (2006) but also a chance to discover influencing factors that are not obvious from the start (Paper A).

  - Furthermore, the author proposes to add a request for reflections on the decision-making process and what is happening in each of the five levels of perspective (Paper A) in order to spot other influencing events.
  - The respondents emphasised that they wanted to make a more qualitative judgment of the evaluation results before deciding what alternative to choose (Paper C). The author also proposes to add requests for reflections on the final decision to reinforce the qualitative judgement.
- Introduce questions regarding compatibility of the system, e.g. as an evaluation criteria, which would increase the possibility of taking care of the compatibility issue (Paper C).
- Ask for contextual circumstances, thereby addressing the outlook for future risks (Paper A), e.g. Gidel et al (2005) address the risk management in decision making on new product design
- Since the template is used in interfaces between different roles and different organisational levels in the concept decision-making process, it should be designed to support that communication (Paper C).
- Be easy to learn, understand and apply (Norell, 1992). For example Pugh's matrix method (Pugh, 1990) is considered to be easy to understand (Weiss and Hari, 1997; King and Sivaloganathan, 1999; Salonen and Perttula, 2005). Additionally, King and Sivaloganathan (1999) emphasise the benefits of using a graphical template such as the QFD-matrix.
- Handle coupled decisions (Paper A) since most real-world problems include interconnections (March, 1997; King and Sivaloganathan, 1999).
- Address the need for new innovations (Paper C) by assessing the innovation potential (Justel et al, 2007).
- In addition to this, also fulfil requirements for working procedures on a general level, for example containing accepted non-trivial knowledge within the area of interest; create common references and shared views; and provide possibilities to personal growth and learning (Norell, 1992).

Therefore, the author concludes that another key to more successful concept decision making is to have and apply relevant *methods*, i.e. relevant supporting working procedures in general and templates for evaluating alternative solutions in particular.

Mindset and methods

Summing up this section, the author concludes that key pragmatic means for improving concept decision-making are developing the right *mindset* and applying right *methods*. A certain kind of *mindset*, including awareness, attitude and approach, is needed for both management and co-workers working in early product development phases. *Methods* in the form of relevant supporting working procedures, designed to support the product development work in practice, must be available. It is the author's proposal that both *mindset* and *methods* need to be carefully considered when developing future improvements of the concept decision-making process.

One of the many challenges relates to a company's internal formal working procedures - how to model a method or working procedure to really support operations, not just show overview models? Another challenge is to capture the really essential information regarding already proposed methods in theory when using them as a base for developing new methods and supporting working procedures in companies. Finally, a main challenge for the development of working procedures is how to support the more informal factors, like attitudes and climate, since the author thinks common ways to formalise the process (e.g. using a stage gate process) should not be used. Instead focus should be placed on creating and designing interfaces between people in the process to ensure that optimal interaction takes place.

5.6 Revisiting the research questions

Below there is a brief discussion of what has been found in correspondence to each research question.

RQ1: *What is characterising and what factors are influencing the concept decision-making process in large companies, considering the whole system composed of structure, technologies and social aspects?*

The concept decision-making process was found to be challenging in many ways: anything can change, difficult to develop parallel alternatives, difficult to compare alternatives with different maturity levels, and much time spent on compromising. An initial list of factors that influence the concept decision-making process in large companies was identified: *Project and product request, Supporting structures and routines, Individual competence and driving forces, Teamwork and company culture* and *Contextual circumstances,* and it was confirmed that both formal and informal factors had influence.

RQ2: *How should the concept decision-making process be managed in practice, and what pragmatic improvements are found, considering the new knowledge on characteristics and factors?*

Investigations addressing how the concept decision-making process should be managed were just initiated during the first part of the research project; the main work addressing this research question will be performed in the second part of the overall research project. Regarding how to improve the concept decision-making process it was found in the empirical studies that different perspectives (*individual*, *team*, *project*, *organisation* and *context*) have to be taken into consideration. When discussing pragmatic improvements for management of the concept decision-making process, the initial study on this matter indicated that the first step is to focus on developing the *mindset* (individual and team level: fostering an open climate) and applying *methods* (organisation level: provide sufficient administrative support).

5.7 Quality of the research results

In this section validity, reliability, generalisability and insider research are treated in order to discuss the quality of the research presented in this licentiate thesis.

Validity

Validity means whether the research actually has investigated what is intended to investigate and if the findings are 'really' about what they appear to be about (Kvale, 1983; Patel and Davidson, 2003). To ensure the validity of the research the author strived for a research design that contributed to fulfilling the purpose. For example, semi-structured interviews were used to obtain the respondents' answers and opinions, respondents were carefully selected, and the interviews took place in two different companies. In addition, two interview studies were performed in the same company at two different occasions (two years apart). Triangulation in the analysis was used through utilising the supervisors. All in all, the results and conclusions from the first part of the research project will be verified and validated through the planned activities in the second part of the research project. Additionally, in order to keep an industrial focus in the research, a Reference group (involving senior and experienced people) is appointed in the company, with discussions held right from the beginning of the research project. These discussions have sometimes highlighted issues that might otherwise have been overlooked, or not getting enough attention. Finally, the discussions have contributed to better understanding of ongoing political currents in the organisation.

Reliability

In quantitative research *reliability* means whether the research work is performed in a reliable way (Robson, 2002; Patel and Davidson, 2003). Reliability in qualitative research should instead be seen in the context of the unique situation that is present when the research is conducted (Patel and Davidson, 2003). In qualitative research reliability is not only about being thorough, careful and honest in carrying out the research, but also about being able to show others what has been done, i.e. providing proper descriptions and documentations of the research process (Yin; 1994, Robson, 2002). The author has strived to provide this in all parts of the research, such as data collection and data analysis.

Generalisability

Generalisability refers to the extent to which findings of the enquiry are more generally applicable outside the studied situation (Robson, 2002), which might be somewhat problematic in qualitative research (Patel and Davidson, 2003). The goal of generalisability can also be questioned in this research project since the overall approach is action research with the aim to create value for the specific context that is researched (Westlander, 1999). However, a qualitative analysis can lead to understanding of a phenomenon and what variations this phenomenon shows in relation to its context, and therefore generalisations may be made for similar situations and contexts (Patel and Davidson, 2003). Therefore, the author modestly proposes that the results presented here provide valuable and useful insights and elucidate relevant phenomena that are interesting for both practitioners and other researchers.

Insider research

The research project is performed as an Industrial PhD project and therefore the issue of *insider research* deserves an explicit discussion. Insider research has specific benefits (such as closeness to the organisation, pre-understanding, access to interesting events) and as such reduces the risk of misunderstandings through close and daily communication (Björk, 2003; Mikaelsson, 2004). There are also challenges, such as when the researcher (in this case research student, i.e. the author) is employed in the studied organisation (Guide, 2007). In the set-up for this research project, the benefits identified have been: an understanding and background of the problem; specific knowledge regarding the organisation investigated; and also access to both people and documentation in the organisation. A major challenge identified was that the author might be trapped in preconceived opinions of how things are at the company or how it ought to be. To eliminate this bias, discussions with the supervisors were ongoing during the research (conducting interviews, analysis material and writing papers). In some cases the researcher (the author) was in a position of dependence to the respondents being interviewed, but the author dot not experience this as a hindrance at any time.

6 Conclusions and Future Work

The research presented here contributes with a description of concept decision making in large organisations in practice, based on investigations in Swedish industry.

The concept decision-making process studied was found to have a number of characteristics:

- The people working in concept development are prepared that anything can happen, and that everything can change, i.e. having a specific *concept state of mind*.
- Many parallel product systems being in concept development at the same time, which creates large number of interfaces that have to be considered.
- Difficulties were found in conducting a proper evaluation of alternative solutions within each product system, e.g. only one alternative was developed, or the fact that the alternative solutions had different maturity levels.
- The process included much time spent on compromising and handling deviations.
- The process revealed can not be described according to rational decision-making theories.
- A major result is that a concept decision is not made at one specific point in time. Instead it is many decisions, activities and actors, on several organisational levels, that add up and result in concept decisions in the investigated organisations. The concept decision-making process was found to be *a web of interconnected activities, with many decisions integrated and embedded in the process* in the regular development work.

Based on the empirical studies presented in this licentiate thesis, it can be stated that concept decisions are influenced by both formal and informal factors: *Project and product request, Supporting structures and routines, Individual competence and driving forces, Teamwork and company culture* and *Contextual circumstances.* The main influencing factors represent different perspectives, which means that the factors have influence on different levels: the *individual* (dependent on the individual's goals, competence etc.), the *team* (interaction between individuals), the *project* (the performance of the specific project), the *organisation* (the prevailing structure and formal processes in the company, which is not project specific) or the *context* (the events in the surrounding world). The knowledge of the different perspectives has implications for how change activities, aiming to improve the decision-making process, should be designed. An example (addressing the individual level of perspective) could be: when assigning a development team, the team members should have different experiences in order to provide a much broader set of personal experiences.

It was discussed whether the available engineering design literature on concept development and evaluation is sufficient in supporting industrial practice, and a gap between theory and practice has been pointed out in previous research. However, the author claims that the internal formal working procedures (a common element in large organisations) have not been discussed in a sufficient way in previous engineering design research, and should therefore be addressed when discussing change management and the theory-practice gap. Furthermore, the engineering design literature should be challenged to improve ways of visualising and communicating the complexity in product development models, and companies should be challenged to be made more aware of the implications and role of their internal formal working procedures.

Means for improving the concept decision-making process were discussed in an in-depth study conducted in the case organisation, and it was concluded there that the strongest pragmatic means for improvement were developing *mindset* and applying *methods*. Therefore these two areas should be initially focused when defining improvements of the concept decision-making process:

- *Mindset* addresses the awareness, attitude and approach needed not only by management, but also by co-workers, when working in early product development phases: how to raise awareness of what influences concept decision making; eliminate organisational barriers and communicate the brand and organisational vision; encourage action and allow mistakes, only penalising inaction.
- *Methods* mainly addresses templates for evaluating alternative solutions, but also the role descriptions for system experts. It was concluded that these documents were obligatory passage points in the concept decision-making process at the investigated company, and therefore the design of the documents can have a large impact in the process. A template for evaluating alternative solutions in early product development phases ought to be, for example in a matrix form; a combination of logic and qualitative reasoning; easy to understand; preferably in graphical layout; and to include questions regarding innovativeness, risk assessment, compatibility, decision rationale and reflections.

The conclusions provided here are based on a limited empirical base (three studies, two companies) but the author suggests that the investigated organisations mirror the situation for several other organisations. Therefore, without any claims that the results are general for all decision-making organisations, the author thinks that the findings elucidate a number of interesting issues for product developing organisations in general.

6.1 Future work

The research presented here has concluded the first part of the research project, and has focused on understanding concept decision making and on identifying means for improvements. In the second part of the overall project, enhanced supporting working procedures and actions for change will be defined and developed. The plan is also to implement the new working procedure in the organisation where the project was initiated, in order to test the research result in practice, and to create change in the organisation.

Several findings from the first part of the project will be used as a base for the next step in the overall research project. It was found that the five different perspectives (*individual, team, project*, *organisation* and *context*) and the three entities *theory, formal working procedures* and *practice* must be taken into consideration when defining proposals for improving the concept decision-making process. It was also found that the strongest pragmatic means for improvement were to be developing the right *mindset* for concept development, whilst at the same time providing and applying relevant supporting *methods*, i.e. working procedures and templates. Consequently, these two areas, developing the mindset for management of the concept development and improving and applying the template for evaluating alternative solutions, will be focused on in the remainder of the overall research project, maintaining an action research approach.

The future work in the overall research project is about developing working procedures and methods. A challenge will be not to stumble on the same obstacles that the author has criticised the available methods (with low utilisation) and existing literature for. Therefore, the author will try to create something that considers more issues than supporting methods for the management of concept development and the evaluation of alternative solutions provide today. Creating change in the researched organisation, the theory-practice-gap also will be addressed through the action research approach.

7 References

Ahn, H. and Dyckhoff, H. (1997) A flexible concept for decision support: Evaluation and selection of suitable product development activities. *European Journal of Operational Research*, 100(2), 266-276.

Andersson, F. (2003) *The Dynamics of Requirements and Product Concept Management*. PhD thesis, Department of Product and Production Development, Chalmers University, Gothenburg.

Andreasen, M.M. and Hein, L. (1987) *Integrated Product Development*. IFS Publications Ltd / Springer-Verlag, Bedford.

Araujo, C.S. and Benedetto-Neto, H. (1996) The utilization of product development methods: A survey of UK industry. *Journal of Engineering Design*, 7(3), 265-277.

Avigad, G. and Moshaiov, A. (2008) Set-based concept selection in multi-objective problems: optimality versus variability approach. *Journal of Engineering Design*.

Ayag, Z. and Özdemir, R.G. (2009) A hybrid approach to concept selection through fuzzy analytic network process. *Computer and Industrial Engineering*, 56(1), 368-379.

Backman, M., Börjesson, S. and Setterberg, S. (2007) *Working with concepts in the fuzzy front end: exploring the context for innovation for different types of concepts at Volvo Cars*. R&D Management, 37(1), 17-28.

Badke-Schaub, P. & Gehrlicher, A. (2003) Patterns of Decisions in Design: Leaps, Loops, Cycles, Sequences and Meta-processes. Proceeding of *14th International Conference on Engineering Design ICED'03*, Stockholm.

Baker, K.G. and Albaum, G.S. (1986) Modeling New Product Screening Decisions. *Journal of Product Innovation Management*, 3(1), 32-39.

Beskow, C. and Ritzén, S. (2000) Performing Changes in Product Development: A Framework with Keys for Industrial Application. *Research in Engineering Design*, 12(3), 172-190.

Bettman, J.R., Luce, M.F. and Payne, J.W. (1998) Constructive Consumer Choice Processes. *Journal of Consumer Research*, 25(3), 187-217.

Björk, E. (2003) *Insider Action research – Applied on Development of Assistive Products*. PhD thesis, Institute of Machine Design, Otto-von-Guericke-University, Magdeburg.

Blessing, L. (1994) *A process-based approach to computer supported engineering design*. PhD thesis, University of Twente, published Cambridge 1994.

Blessing, L., Chakrabarti, A. and Wallace, K. (1995) A Design Research Methodology. Proceedings of *10th International Conference on Engineering Design ICED'95*, Praha.

Blessing, L. (2002) What is this thing called Design Research? *Annals of 2002 Int'l CIRP Design Seminar*, Hong Kong.

Blessing, L. (2008) Lecture at *10th Summer School on Engineering Design Research*, Malta.

Bragd, A. (2002) *Knowing Management: an ethnographic study of tinkering with a new car*. Bas Publisher, Gothenburg.

Chin, K. and Wong T.N. (1999) Integrated product concept development and evaluation. International *Journal Computer Integrated Manufacturing*, 12(2), 179-190.

Christensen, J.K. and Varnes, C.J. (2006). The ignorance of Information at Gate Meetings. *Proceeding of 13th International Product Development Management Conference*, Milan.

Christiansen, J.K. and Varnes C.J. (2007) Making Decisions in Innovation: Meetings or Networks? *Creativity and Innovation Management*, 16(3), 282-297.

Cooper, R.G. (2001) *Winning at New Products: Accelerating the Process from Idea to Launch,* 3rd ed. Reading. Perseus Books, MA.

Cooper, R.G. (2008) The Stage-Gate Idea-to-Launch Process-Update, What's New, and NexGen Systems. *Journal of Product Innovation Management*, 25(3), 213-232.

Cross, N. (2000) *Engineering Design Methods – Strategies for Product Design*, 3rd ed. John Wiley & Sons Ltd, Chichester.

Cross, N. (2006) *Designerly Ways of Knowing*. Springer-Verlag, London.

Dwarakanath, S. and Wallace, K.M. (1995) Decision-making in engineering design: Observations from design experiments. *Journal of Engineering Design*, 6(3), 191-207.

Eisenhardt, K.M. (1989a) Making Fast Strategic Decisions in High-Velocity Environments. *The Academy of Management Journal*, 32(3), 543-576.

Eisenhardt, K.M. (1989b) Building Theories from Case Study Research. *The Academy of Management Review*, 14(4), 532-550.

Eisenhardt, K.M. and Graebner, M.E. (2007) Theory Building from Cases: Opportunities and Challenges, *Academy of Management Journal*, 50(1), 25-32.

Eisenhardt, K.M. and Zbaracki, M.J. (1992) Strategic Decision Making. *Strategic Management Journal*, 13, 17-37.

Ekvall, G. (1996) Organizational Climate for Creativity and Innovation. *European Journal of Work and Organizational Psychology*, 5(1), 105-123.

Engwall, M. (2003) Mysteriet med den orimliga modellen: Om utvecklingsmodeller, kunskap och kontroll (In Swedish). *Nordiska organisasjonsstudier*, 5(4), 28-53.

Eriksson, J. (2009) *Collaborative product development - a collaborative decision-making approach*. Licentiate thesis, School of Innovation, Design and Engineering, Mälardalen University, Eskilstuna.

Gandy, A., Jäger, P., Bertsche, B. & Jensen, U. (2006) Decision support in early development phases – A case study from machine engineering. *Reliability Engineering and System Safety*, 92(7), 921-929.

Garcia, R. and Calatone, R. (2002) A critical look at technological innovation typology and innovativeness terminology: a literature review. *Journal of Product Innovation Management*, 19(2), 110-132.

Gidel, T., Gautier, R. and Duchamp, R. (2005) Decision-making framework methodology: an original approach to project risk management in new product design. *Journal of Engineering Design*, 16(1).

Gilovich T., Griffin D. and Kahneman D. (2002) *Heuristics and Biases, The Psychology of Intuitive Judgment*. Cambridge University Press, New York.

Girod, M., Elliot, A.C., Burns, N.D. and Wright, I.C. (2003) Decision making in conceptual engineering design: an empirical investigation. Proceedings of *the Institution of Mechanical Engineers - Part B - Engineering Manufacture*, 217(9), 1215-1228.

Gries B. (2007) *Design Flaws and Quality-Related Feedback in Product Development*. PhD thesis, Technical University of Berlin, Berlin.

Guide Jr, A.D.R. and Van Wassenhove, L.N (2007) Dancing with the Devil: Partnering with Industry but Publishing in Academia. *Decision Sciences,* 38(4), 531-546.

Gutiérrez E., Ölundh Sandström G., Janhager J. and Ritzén S. (2008) Innovation and decision making: understanding selection and prioritization of development projects. In the *4th IEEE International Conference on Management of Innovation & Technology*, Bangkok.

Hammond, J.S., Keeney, R.L. and Raiffa, H. (1998) The Hidden Traps in Decision Making. *Harvard Business Review*, 76(5), 47-58.

Hansen C.T. and Andreasen M.M. (2002) The content and nature of a design concept, *NordDesign 2002*, Trondheim.

Hansen C.T. and Andreasen M.M. (2004) A mapping of design decision-making. Proceedings of *8th International Design Conference, DESIGN 2004*, Dubrovnik.

Hein, L. (1994) Design Methodology in Practice. *Journal of Engineering Design*, 5(2), 165-181.

Janhager, J., Persson, S. and Warell, A. (2002) Survey on Product Development Methods, Design Competencies, and Communication in Swedish Industry. Proceedings of *the 4th International Symposium on Tools and Methods of Competitive Engineering*, China.

Jansson, D.G. and Smith, S.M. (1991), Design Fixation, *Design Studies*, 12(1), 3-11.

Justel, D., Vidal, R., Arriaga, E., Franco, V. and Val-Jauregi, E. (2007) Evaluation method for selecting innovative product concepts with greater potential marketing success. Proceedings of the *16th International Conference on Engineering Design, ICED´07*. August 28-31, Paris.

Kahneman D. and Tversky A. (2000) *Choices, Values and Frames*. Cambridge University Press, New York.

Khurana, A. and Rosenthal, S.R. (1997) Integrating the Fuzzy Front End of New Product Development. *Sloan Management Review*, 38(2), 103-120.

Khurana, A. and Rosenthal, S.R. (1998) Towards Holistic "Front Ends" In New Product Development. *Journal of Product Innovation Management*, 15(1), 57-74.

King, A.M. and Sivaloganathan, S. (1999) Development of a Methodology for Concept Selection in Flexible Design Strategies. *Journal of Engineering Design*, 10(4), 329-349.

Koen, P., Ajamian, G., Burkart, R., Clamen, A., Davidson, J., D'Amore, R., Elkins, C., Herald, K., Incorvia, M., Johnson, A., Karol, R., Seibert, R., Slavejkov, A. and Wagner, K. (2001) Providing clarity and a common language to the "Fuzzy Front End". *Research - Technology Management*, 44(2), 46-55.

Koopman, P. and Pool J. (1991) Organizational Decision Making: Models, Contingencies and Strategies. I.J. Rasmussen, B. Brehmer and J. Leplat (Red.), *Distributed decision making: Cognitive models for cooperative work* (pp 19-46). Wiley, West Sussex.

Krischnan, V. and Ulrich, K.T. (2001) Product Development Decisions: A review of the Literature. *Management Science*, 47(1), 1-21.

Kvale, S. (1983) The Qualitative Research Interview: A Phenomenological and a Hermeneutical Mode of Understanding. *Journal of Phenomenological Psychology*, 14(2), 171-196.

Kvale, S. (1997) *Den kvalitativa forskningsintervjun,* (in Swedish). Studentlitteratur, Lund.

Lenéer-Axelsson, B. and Thylefors, I. (1991) *Arbetsgruppens psykologi*, (in Swedish). Natur och Kultur, Stockholm.

López-Mesa, B. and Chakrabarti, A. (2007) A model of decision-making knowledge in conceptual design. Proceedings of the *16th International Conference on Engineering Design ICED'07*, Paris.

March, J.G. (1997) Understanding how decisions happen in organizations. I.Z. Shapira (Red.), *Organizational decision making. Cambridge series on judgment and decision making* (pp 9-32). Cambridge University Press, New York.

March, J.G. and Simon, H.A. (1958) *Organizations*. John Wiley & Sons Inc. New York.

Marks, A.P. (1989) The Sinclair C5 - An Investigation into its Development, Launch and Subsequent Failure. *European Journal of Marketing*, 23(1), 61-71.

Menzel, H., Aaltio, I. and Ulijn, J.M. (2007) On the way to creativity: Engineers as intrapreneurs in organizations. *Technovation*, 27(12), 732-743.

Mikaelsson, J. (2004) *Developing Managerial Work – A system and work-flow approach*. PhD thesis, Department of Project Management, Chalmers University of Technology, Gothenburg.

Morgan, J.M. and Liker, J.K. (2006) *The Toyota Product Development System*. Productivity Press, New York.

Nevins, J.L. and Whitney, D.E. (1989). *Concurrent design of products and processes: a strategy for the next generation in manufacturing*. McGraw-Hill, New York.

Ng, K.W. (2006) A critical analysis of current engineering design methodologies from a decision making perspective. Proceedings of *Innovative Production Machines and Systems, IPROMS 2006*, virtually.

Nicholson, G.C. (1998) Keeping innovation alive. *Research – Technology Management*, 41(3), 34-40.

Norell, M. (1992) *Stödmetoder och samverkan i produktutvecklingen*, (in Swedish). PhD thesis,

Department of Machine Elements, KTH, Stockholm.
Nutt, P.C. (1984) Types of organizational decision processes. *Administrative Science Quarterly*. 29(3), 414-450.
Nutt, P.C. (1999) Surprising but true: Half of the decisions in organizations fail. *Academy of Management Executive*, 13(4), 75-90.
Otto, K.N. (1995) Measurement Methods for Product Evaluation. *Research in Engineering Design*, 7(2), 86-101.
Pahl, G. and Beitz, W. (1996) *Engineering Design – A systematic approach*. Springer-Verlag, Berlin, Germany.
Patel, R. and Davidson, B. (2003) *Forskningsmetodikens grunder*, (in Swedish). Studentlitteratur, Lund.
Patton, J.R. (2003) Intuition in decisions. *Management Decision*, 41(10), 989-996.
Payne, J.W. (1982) Contingent decision behavior. *Psychological Bulletin*, 92(2), 382-402.
PDMA, (2005). *The PDMA handbook of new product development*, 2nd ed, edited by K.B. Kahn. John Wiley & Sons Inc, Hoboken.
Pugh, S. (1990) *Total Design – Integrated Methods for Successful Product Engineering*. Addison-Wesley Publishing Company, Wokingham.
Reid, S.E. and de Brentani, U. (2004) The Fuzzy Front End of New Product Development for Discontinuous Innovations: A Theoretical Model. *Journal of Product Innovation Management*, 21(3), 170-184.
Reidenbach, R.E. and Grimes, S. (1984) How Concept Knowledge Affects Concept Evaluation. *Journal of Product Innovation*, 1(4), 255-266.
Reinertsen, D.G. (1999) Taking the Fuzziness Out of the Fuzzy Front End. *Research – Technology Management*, 42(6), 25-31.
Robson, C. (2002) *Real World Research - A Resource for Social Scientists and Practitioner-Researchers*. Blackwell Publishing, Oxford.
Roozenburg, N.F. M. and Eekels, J. (1995) *Product Design: Fundamentals and Methods*. John Wiley and Sons Ltd, Chichester.
Saaty, T. (1990) How to make a decision: The Analytical Hierarchy Process. *European Journal of Operational Research*, 48(1), 9-26.
Salonen, M. and Perttula, M. (2005) Utilization of concept selection methods – a survey of Finnish industry. Proceedings of *ASME IDETC/CIE 2005*. Long Beach, California, USA, September 24-28.
Setterberg, S. (2008) *Filtrerad Effektivitet: Möjliggörare för Organisatorisk Utveckling*, (in Swedish). Licentiate Thesis. School of Technology Management and Economics, Chalmers University of Technology, Gothenburg.
Simon, H.A. (1955) A behavioral model of rational choice. *Quarterly Journal of Economics*, 69(1), 99-118.
Simon, H.A. (1956) Rational choice and the structure of the environment. *Psychological Review*, 63(2), 129-138.
Sobek, II, D.K., Ward, A.C. and Liker, J.L. (1999) Toyota's Principles of Set-Based Concurrent Engineering. *Sloan Management Review*, 40(2), 67-83.
Stempfle, J. and Badke-Schaub P. (2002) Thinking in design teams – an analysis of team communication. *Design Studies*, 23(5), 473-496.
Suwa, M. Gero, J. and Purcell, T. (2000) Unexpected discoveries and S-invention of design requirements: important vehicle for a design process. *Design Studies*, 21(6), 539-567.
Tatum, B.C., Eberlin, R., Kottraba, C. and Bradberry, T. (2003) Leadership, decision-making, and organizational justice. *Management Decision*, 41(19), 1106-1016.
Taylor, A.J. (1993) The Parallel Nature of Design. *Journal of Engineering Design*, 4(2), 141-152.
Ullman, D.G. (1997) *The Mechanical Design Process*, 2nd ed. McGraw-Hill International Editions, Singapore.

Ullman, D.G. (2002) *12 steps to robust decisions – building consensus in product development and business*. Trafford Publishing, Victoria.

Ulrich, K.T. and Eppinger S.D. (2008) *Product Design and Development*, 4th ed. McGraw-Hill, New York.

Ulrich, Karl T. and Pearson, S. A. (1993). Does product design really determine 80% of manufacturing cost? Working paper 3601-93. *Sloan School of Management*, Cambridge.

van Riel, A.C.R., Lemmink, J. and Ouwersloot, H. (2004) High-technology Service Innovation Success: A Decision-Making Perspective. *Journal of Product Innovation Management*, 21(5), 348-359.

VDI (1986) *VDI Standard Handbook 2221: Systematic Approach to the Design of Technical Systems and Products*. VDI-Verlag, Düsseldorf.

von der Weth R. (1999) Design instinct? – the development of individual strategies. *Design Studies*, 20(5), 453-463.

Ward, A., Liker J.K., Christiano J.J. and Sobek II D.K. (1995) The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster. *Sloan Management Review*, 36(3), 43-61.

Weiss, M.P. and Hari A. (1997) Problems of concept selection in real industrial environment. Proceedings of *the 11th International Conference on Engineering Design, ICED'97*, Tampere, Finland.

Westlander, G. (1999) *Forskarroller i varianter av aktionsforskning*, TRITA-MMK 1999, (in Swedish). Department of Machine Design, KTH, Stockholm.

Whyte, W.F. (ed) (1993) *Participatory Action Research*. Newbury Park: Sage Publications.

Wright, I. C. (1998) *Design Methods in Engineering and Product Design.* McGraw-Hill Publishing Company, Cambridge.

Yates, F. (2001) "Outsider:" impressions of naturalistic decision making. In Salas, E. and Klein, G. (Eds.) *Linking expertise and decision making* (pp 9-33). Lawrence Erlbaum Associates Mahwah, N.J.

Yin, R.K. (1994) *Case study research: design and methods*, 2nd ed. Sage Publications, Thousand Oaks.

Zeelenberg, M., Nelissen, R.M.A., Breugelmans, S.M. and Pieters, R. (2008). On emotion specificity in decision making: Why feelings is for doing. *Judgment and Decision Making*, 3(1), 18-27.