COLLABORATIVE PRODUCT DEVELOPMENT:
A COLLABORATIVE DECISION-MAKING APPROACH

Joakim Eriksson

2009
ABSTRACT

The process of developing products is a central contributor to companies’ competitiveness. Since the mid-20th century, vast efforts have been made to try to support this process through new theories, methodologies, and methods. Today, organisations find themselves in a situation where they need to continuously improve the performance of the product development process in order to stay ahead or even keep up with competitors. The process of developing and producing a product is a knowledge-intense activity influenced by many actors and affecting many actors in the organisation. Thus, most decisions made during product development are collaborative.

A lack of understanding of the nature of decision-making in organisations results in a behavioural pattern of poor decision-making strategies and tactics, which in turn impacts on the performance of the product development process. Currently, no methodology or methods are available for process improvements in product development that focus on decision-making fundamentals and the performance of decisions made within the product development process.

In order to support product development process improvements, it is important to develop knowledge about how the collaborative decision-making process can be viewed holistically (as a system) and include its relation to overall performance. This is the main objective of this research.

The research is based on an extensive literature review and two case studies in three Swedish manufacturing companies with in-house product development. The literature review is summarised in the chapter “Frame of References”. The first case study aimed at understanding the elements and their relations, i.e. a system. The system relates fundamental aspects of decision-making, the product development process, and performance aspects. The second case study aimed at understanding what actors perceive to effect collaborative decision-making. The result was used in relation to theory in order to develop a model of competencies for collaborative decision-making.
I would like to start with expressing my gratitude to my ever inspiring supervisor, Adjunct Professor Björn Fagerström. His commitment to this research work and guiding discussions have served as a source of inspiration and direction throughout these past two and a half years. Secondly, I would like to thank my assisting supervisor, Professor Mats Jackson, for his open-minded mindset as a leader and his trust in my choices throughout this research work. Both Björn and Mats have provided a creative work atmosphere in the research group and always encourage one to strive beyond one’s limits. Thank you both for all your discussions and guidance!

I would also like to thank the people in our research group for their support and encouragement: Mikael Hedelind, Erik Hellström, Antti Salonen, Anna Granlund, Yuji Yamamoto, Dr. Sofi Elfving, Dr. Marcus Bengtsson, Carina Andersson, Anders Wikström, Jennie Andersson, Adjunct Professor Monica Bellgran and Mats Deleryd. You all make the research work interesting and fun!

I would especially like to thank Stefan Johnsson and Dr. Rolf Olsson for their commitment to our common research interest of performance in product development. Our common goal and different backgrounds became the basis for inspiring creative thinking. Thank you both. I am looking forward to continuing our collaboration!

Also, Annette Brannemo at VCE Components deserves a big Thank You for the support she has given. Our cooperation has provided me with invaluable ideas and feedback on findings and thoughts.

Further, I would like to extend my sincere gratitude to the companies that provided the opportunities for conducting research through industrial cases, as well as the kind people in companies who provided general discussions and insight about different industrial situations. Among the companies are: LogMax AB, VCE Components, JAPS Elektronik AB, ABB Robotics, and Uponor AB.

Last, but not least, I would like to send my love to my family and friends for their friendship and support in my “other” life which runs beside the “research life”.

ACKNOWLEDGEMENTS
PUBLICATIONS

LIST OF INCLUDED PUBLICATIONS


ADDITIONAL PUBLICATIONS


# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>III</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>V</td>
</tr>
<tr>
<td>Publications</td>
<td>VII</td>
</tr>
<tr>
<td>Table of Contents</td>
<td>IX</td>
</tr>
<tr>
<td>Introduction and Positioning</td>
<td>11</td>
</tr>
<tr>
<td>Collaborative Product Development</td>
<td>11</td>
</tr>
<tr>
<td>Problem Statement</td>
<td>13</td>
</tr>
<tr>
<td>Objective</td>
<td>14</td>
</tr>
<tr>
<td>Research Questions</td>
<td>15</td>
</tr>
<tr>
<td>Delimitations</td>
<td>16</td>
</tr>
<tr>
<td>Practical and Academic Relevance</td>
<td>17</td>
</tr>
<tr>
<td>Research Methodology</td>
<td>19</td>
</tr>
<tr>
<td>Research within Design Science</td>
<td>19</td>
</tr>
<tr>
<td>Research on Decision-Making</td>
<td>21</td>
</tr>
<tr>
<td>Research Project Design</td>
<td>22</td>
</tr>
<tr>
<td>Scientific Approach</td>
<td>23</td>
</tr>
<tr>
<td>Research Strategy - Case Studies</td>
<td>25</td>
</tr>
<tr>
<td>Methods for Collecting and Analysing Data</td>
<td>26</td>
</tr>
<tr>
<td>The Research Process</td>
<td>26</td>
</tr>
<tr>
<td>The Quality of the Research</td>
<td>28</td>
</tr>
<tr>
<td>Validity</td>
<td>29</td>
</tr>
<tr>
<td>Reliability</td>
<td>29</td>
</tr>
<tr>
<td>Frame of References</td>
<td>31</td>
</tr>
<tr>
<td>The Process of Developing Products</td>
<td>31</td>
</tr>
<tr>
<td>What is product development performance?</td>
<td>34</td>
</tr>
<tr>
<td>Improving the Process of Developing Products</td>
<td>36</td>
</tr>
<tr>
<td>Decision-Making in a Product Development Context</td>
<td>39</td>
</tr>
<tr>
<td>What is a decision and decision-making?</td>
<td>39</td>
</tr>
<tr>
<td>What is a good decision?</td>
<td>40</td>
</tr>
<tr>
<td>Decision-Making in Product Development Literature</td>
<td>41</td>
</tr>
<tr>
<td>Different Views of Decision-Making in Product Development</td>
<td>43</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Collaborative Decision-Making in Product Development</td>
<td>47</td>
</tr>
<tr>
<td>Decision Management and Decision Support in Product Development</td>
<td>53</td>
</tr>
<tr>
<td>Reflections on the Theory</td>
<td>57</td>
</tr>
<tr>
<td><strong>EMPIRICAL STUDIES</strong></td>
<td>61</td>
</tr>
<tr>
<td>Research Clarification – Case Study in Company X &amp; Y</td>
<td>61</td>
</tr>
<tr>
<td>Background and Problem Statement</td>
<td>61</td>
</tr>
<tr>
<td>Empirical Findings in the Research Clarification Case Study</td>
<td>62</td>
</tr>
<tr>
<td>Reflection and Conclusions from the Research Clarification Case Study</td>
<td>65</td>
</tr>
<tr>
<td>The Descriptive Case Study</td>
<td>71</td>
</tr>
<tr>
<td>Background and Problem Statement</td>
<td>71</td>
</tr>
<tr>
<td>Empirical Findings in the Descriptive Case Study</td>
<td>72</td>
</tr>
<tr>
<td>Reflection and Conclusions from the Descriptive Case Study</td>
<td>75</td>
</tr>
<tr>
<td><strong>CONCLUSIONS, CONTRIBUTION, AND FUTURE WORK</strong></td>
<td>81</td>
</tr>
<tr>
<td>Conclusions</td>
<td>81</td>
</tr>
<tr>
<td>Fulfilment of Objectives</td>
<td>82</td>
</tr>
<tr>
<td>Contribution</td>
<td>83</td>
</tr>
<tr>
<td>Quality of the Research and Validity of the Results</td>
<td>84</td>
</tr>
<tr>
<td>Future Work</td>
<td>85</td>
</tr>
<tr>
<td>Best practice of collaborative decision-making</td>
<td>85</td>
</tr>
<tr>
<td>Formal and informal activities of collaborative decision-making</td>
<td>85</td>
</tr>
<tr>
<td><strong>REFERENCES</strong></td>
<td>87</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION AND POSITIONING

This first chapter focuses on the question; “Why focus on collaborative decision-making?”. It describes the background of the research, and presents the problem statement, objective, delimitations, and practical and academic relevance of the research. The outline of the thesis is also presented.

Collaborative Product Development

In the beginning of the 20th century, Henry Ford introduced a product development management style that still influences our way of managing product development in the Western World. The hierarchical management system of organisations builds upon the fact that top management knows what is needed to be done and how. Top management then uses the chain of command to lead and guide the activities with precision in order to produce a product as quickly and cost efficiently as possible. Technological advances in the 1940-50’s resulted in projects becoming more complex and the US military developing Systems Engineering [1] and Concurrent Engineering [2] in order to manage the large scale, complex, product development projects which they undertook. The product architecture and the development activities needed to be connected and coordinated in order to oversee the whole of the development and produce a product in a short period of time. During the 1970’s, Pahl and Beitz [3] introduced a systematic approach to Engineering Design in order to improve the design approach and methods used by engineering designers. They introduced a systematic approach to product development in the form of a methodology1. Several more researchers followed, developing the methodology further, e.g. Ulrich and Eppinger, [4] and Ullman [5]. In the 1980’s, Freddy Olsson [6] introduced a new approach

for product development management focusing on the collaborative aspect of product development. Product development was seen as a social process that needed to be coordinated, as well as the development of the product architecture. Andreasen and Hein [7] followed in the late 1980’s, introducing the concept of Integrated Product Development. Later, Cooper [8] introduced and trademarked the Stage Gate Model in order to give top management of large corporations a better ability to manage the product development process. The Stage Gate Model was based on a resource management model developed by NASA in the 1960s, and was called PPP (Phased Project Planning). It has been called the world’s first stage gate model [9, 10].

The evolution of the different presented product development approaches shows that when the products get increasingly complex, as well as the size of the organisation necessary to produce them grows, it results in the need to manage the integration and collaboration aspect of the development process. Somewhat simplified, in conclusion, making successful decisions gets increasingly difficult when the decisions demand the input from, and affect, many different actors. Some of the later management concepts for product development were designed to support these difficulties, and did so to some extent. Modern product development methodologies include most of the necessary ingredients from systems engineering, concurrent engineering, integrated product development, and the Stage Gate. However, the difficulty of managing the integration of actors’ knowledge in groups in order to make collaborative decisions is not yet overcome, and the pace and complexity of product development is still increasing in many businesses. Today we often refer to “knowledge-intense” product development [11], which demands the integration of many actors’ different knowledge and expertise in order to develop a high-technological product. The need to be able to make collaborative decisions that contribute to the overall success of the developed product still increases in importance.

Jankovic [12] (p.15), describes the implications of a modern collaborative industrial environment during the product development process: “In this process, every actor has specific objectives defined for his domain of action. Therefore, collaborative decision-making is a process where actors have different and often conflicting objectives. Actors in the collaborative decision-making process also have different knowledge concerning the problem as well as different information and points of view.”

The need to integrate and make use of different actors’ knowledge and expertise during decision-making makes the process of developing products difficult. Product development in particular imposes a challenge through the need to integrate inputs from unrelated and distant sources of information in an organisation during the decision-making process. Simon [13] and Busby [14] identified some of the related difficulties within the decision-making process during product development. They showed for example how actors failed to
integrate different actors’ knowledge, not communicating assumptions, not considering other actors’ objectives, not considering consequences of other actors’ actions, and not defining scopes of tasks.

Simon [13] advocates a systematic approach to implementing changes in the decision-making process of a product development organisation in order to introduce the changes in a timely and profitable manner.

**Problem Statement**

On the 25th of January, 2007, a fellow PhD student (today a PhD) and I held a workshop addressing current and future industrial challenges within product development with 19 representatives from nine large companies located in the surrounding area of Stockholm, Sweden. The area of most interest, and the most frequently discussed topic, was about collaboration, i.e. the issue of collaboration within the company as well as outside the company. The common conclusion in the workshop was that while the technological aspects of product development can often be solved by the organisations themselves, there is a great need for external thoughts and support regarding the aspect of collaboration within product development.

This conclusion is supported by the literature which describe that organisations find themselves in a situation where they need to continuously improve the performance of the product development process in order to stay ahead or even keep up with competitors. The process of developing and producing a product is a knowledge-intense activity influenced by many actors and affecting many actors in the organisation. This kind of process has both quantitative and dynamic complexity that, if not treated as different interacting systems, is difficult for people in the organisation to manage. These systems are broken down into sub systems and dependencies are managed as a whole. This is done in order to realise a desired level of organisational performance. Each decision made must be related to the overall competitiveness of the organisation as a whole. Haffey states: “… organisations must address and overcome situations where departmental functions and activity resources optimise their solutions or outputs to satisfy goals that do not reflect or contribute to the satisfaction of the higher-order goals associated with an organisation. In order to promote the degree of integration attained throughout an organisational system, each individual process, activity, resource and decision must be considered from a more holistic organisational perspective and subsequently be coalesced effectively within the organisation system in order to support the realisation of desired degree of organisational performance” [15] (p.2).

According to Yates [16], a lack of understanding of the nature of decision-making in organisations is the problem. This results in a behavioural pattern of failure-prone decision-making strategies and tactics that in turn impact on the performance of the product
development process. Currently, there is no methodology or methods available to “process improvers” in product development that focus on decision-making fundamentals in order to improve the performance of decisions made within the product development process. Yates describes a suitable analogy: “At a superficial level, everyone understands what hitting a golf ball entails. (“You just swing that stick, right?”) At a similar level of superficiality, everybody knows what decision problems are and what solving them entails. Unfortunately, superficial understanding typically is insufficient for guiding intelligent and effective efforts to either strike golf balls or manage decisions. Also unfortunately, all too often, managers have no more than a vague grasp of the true nature of decision problems and processes” [16] (p.10).

In summary, this thesis concludes that there is a lack of knowledge of collaborative product development process improvements that focus on generic decision-making abilities in relation to overall process performance. In order to support product development process improvements, it is important to develop knowledge about how the collaborative decision-making process can be viewed holistically (as a system) and include its relation to performance. This is the main focus and the identified problem area of the research presented in this thesis.

Objective

Based on the problem statement, the objective of this research is to enhance the knowledge of collaborative product development process improvements that focus on generic decision-making abilities in relation to overall process performance.

The approach in this research is to view decision-making from a fundamental level and investigate the implications it has on process improvement efforts. The analysis is conducted in order to understand the nature and success of the overall decision-making ability of groups of actors. The aspect of what decision-making success is and how to measure the success in order to improve decision-making is an important part of this research. Further, the relationship between decision-making success and product development process success is vital to clarify in order to create a decision-making system within a product development context.

This research investigates the concept of collaborative decision-making, which includes knowledge from research areas outside engineering design. Except for engineering design science, organisational and decision science, for example, will be investigated in order to gain knowledge of organisational decision-making models and behaviour to apply in collaborative product development process improvements.
Research Questions

To be able to meet the objective of this research, which is to enhance the knowledge of the collaborative decision-making process by focusing on decision-making fundamentals in relation to overall process performance, a set of three research questions are proposed below.

| RQ1 – What is decision management in collaborative product development? |

The first research question is posed to investigate what is needed in order to manage decision-making fundamentals, decision-making success, and the relation to the collaborative product development process.

The result from RQ1 reveals that there is little written about these aspects as a whole and that decision management is often based on prescriptive models of decision-making. These approaches often relate decision-making to different decision performance aspects, e.g. reaching consensus, or satisfaction. The models of decision management do not relate to product development process performance. Product development methodology is often the basis for process improvements and describes the product development process from different views, e.g. the product lifecycle, concurrent engineering, design phases, or engineering phases. When relating product development processes to decision-making and performance, there are several aspects of particular interest: objectives, uncertainty, preferences, alternatives, criteria, decision-making structures and processes, communication, and decision environment.

| RQ2 – What are the major elements and factors of collaborative decision-making in product development? |

The second research question is posed, based on the result of RQ1, in order to investigate elements and factors of collaborative decision-making in an organisational context. This research question aims at providing a basis for the third research question by enabling the understanding of how fundamental decision-making aspects relate to decision-making performance within a product development organisational context.

The result from RQ2 reveals two major factors of difficulties of collaborative decision-making: awareness of decision-making fundamentals, and the relationship between collaborative decision-making aspects and decision-making performance. The results provide two different aspects of how to analyse decision-making in a product development organisational context: (1) the specification of the organisational landscape and its relation to performance, and (2) the selection of an appropriate decision-making model in order to
analyse relevant decision-making aspects. The case study resulted in the development of a decision-making system of collaborative product development (see Figure 15).

**RQ3 – What factors do actors perceive to effect a collaborative decision in product development, and how do the factors relate to the decision-making literature?**

The third research question is posed in order to investigate what actors perceive to effect decision-making abilities of a product development group, and thereby enhance the knowledge of the nature of naturalistic collaborative decision-making. The research question also aims at ensuring that a real industrial problem is investigated in this research work.

The result from RQ3 identifies actors’ views of the collaborative decision-making process and different aspects of collaborative decision-making in a product development organisational context: (1) awareness of decision-making fundamentals, (2) use of decision-making strategies and tactics, (3) awareness of influencing factors of decision-making, and (4) awareness of the relationship between collaborative decision-making aspects and decision-making performance.

**Delimitations**

This research is focused on Swedish multinational organisations involved in knowledge-intense in-house product development that results in physical artefacts. This type of product development, often called Complex Product Development, includes two types of complexities: dynamic and quantitative. This type of product development is often carried out within large organisations, involving many people within a large diversity of expertise in order to develop a product that often includes mechanics, electronics, and software – also called Mechatronics.

The tasks and activities conducted during product development are increasingly dependent on access to accurate information, extraction, and exchange. Further, decision makers need to identify and include different expertise and perspectives in order to make informed decisions. The amount of information, communication, decision criteria and performance aspects in product development decision-making, together with the fact that there is often no optimal solution obtainable, makes normative and analytical decision support unfit as a solution within this research.

No specific decision-making methods, e.g. specific IT-solutions, are presented in this research, but support methods are treated as an element of collaborative decision-making.
The multi-knowledge research area of decision-making includes research in psychology, which encompasses human cognitive processes. Such processes will not be included in the scope of research. The focus of this research is on the collaborative decision-making process within product development processes and is a matter of the communicative aspect of decision-making – the observable part of decision-making. There are many questions of great importance about the designer’s individual strategy when making decisions: is it a good strategy? Can it be altered? Should it be altered? However, the research described in this thesis will not try to answer those questions. Instead it examines the observable aspects of how groups of people make decisions related to design parameters within the group and together with other groups in a product development organisation. The focus is upon the project manager and his/her interactions with a steering committee, the development group, and external actors. As a result, decision-making will not be included as a human individual process, thereby excluding detailed knowledge about decision-making style and human cognition.

The people in the group include every individual who is a part of resolving an issue controlled by a project steering committee in a product development project and people from different levels and functions in the organisation.

**Practical and Academic Relevance**

There are two different results expected to be derived from this research: a scientific contribution to the research community and a practical and usable contribution to the industrial problem targeted.

The expected scientific contribution of this research includes theoretical and empirical conclusions of the different decision-making models and aspects within, as well as outside, the research area of engineering design. This is to enhance the knowledge of decision-making abilities of groups of actors engaged in product development.

The expected industrial contribution is aimed at increasing the awareness of the importance of collaborative decision-making in industrial situations. All results partially aim at providing industry with the increased ability to handle collaborative decisions.

The long-term objective of this research is to provide a framework that, by focusing on decision-making fundamentals, enables the assessment and minimisation of uncertainties in the product development process in order to continuously customize and improve the product development process. Hopefully, the long term effect is will be an increased ability for companies to introduce changes to the collaborative product development process in a timely and profitable manner.
CHAPTER 2

RESEARCH METHODOLOGY

The second chapter presents the “research journey” of the conducted research and is divided into four sections, called “Research within Design Science”, “Research on Decision-Making”, “Research Design”, and “The Quality of the Research”. The research is aimed at providing results valid for both the industrial and the scientific community (see Figure 1). The chapter describes the methodology used within this research and discusses the quality of the research conducted.

![Figure 1. My research process [17].](image)

Research within Design Science

The objective of this research is to contribute to knowledge about and for designing products, and is therefore a matter of Design Science. Designers and engineers are in a position to effect people’s way of life and are therefore carriers of an important responsibility, “…since their ideas, knowledge and skills determine in a decisive way the technical,
economic and ecological properties of the product” [18] (p.1). Therefore, it is vital to develop an understanding of designing in order to improve the skill and knowledge of actors.

In 1992, Vladimir Hubka and W. Ernst Eder published their book called “Einführung in die Konstruktionswissenschaft” or “Design Science: Introduction to the Needs, Scope and Organization of Engineering Design Knowledge,” as the 1995 English edition was called. The authors introduce the history and sources of knowledge development of designing and outline the research area in the following statement:

The term Design Science is to be understood as a system of logically related knowledge, which should contain and organize the complete knowledge about and for designing. [19] (p.35)

It can be stated that this concept of design science today includes a vast amount of research topics in order to create knowledge about and for designing products, or more described today as the activity of product development.

Hubka and Eder states three goals of Design Science [19]:

Goal area practice: direct improvement of the situation in engineering practice, i.e. in a company or an organization group, or in a project, with two addressees:

- directly to designers
- indirectly in the enterprises (as the superior system)

Goal area science: answering of scientific questions, as for example in a research project or a dissertation;

Goal area education: improvement of design education in the schools.

In a later journal article, Eder [20] divides engineering design knowledge into four categories: practice knowledge, theory knowledge, object knowledge, and process knowledge. The process knowledge category is comprised of knowledge of human activities and theories of human behaviour. Knowledge of human activities is about strategies and tactics when designing, and theories of human behaviour concerns cognitive aspects of designers. It is within the first context (knowledge of human activities) that the research described in this licentiate thesis is positioned.

Further, engineering design can be said to consist of two processes: technical and commercial. The definition of the technical process is producing an artefact and the commercial process is about profit, and so the product “forms the link between the technical and commercial development process” [21] (p.21). In other words, product management focuses on the market and the tradeoffs between customer value and product cost. This ensures the maximisation of the revenue, i.e. the aspect of effectiveness. The purpose of projects within the product development process is to achieve the stated goals with the minimal use of
resources, i.e. the efficiency aspect. There is no effort made in this research to separate the two processes. That is because they are often two trade-off aspects of decisions made in product development.

In fact, the difficulty that presents itself in most, if not all, product development decisions are the tradeoffs between different performance aspects. The performance aspects are often not viewed alike by different levels and departments in organizations, who all try to satisfy their objectives. Collaborative decision-making is defined by Jankovic [12]: “Collaborative decision-making is a collective decision-making where different actors have different and often conflicting objectives in the decision-making process.” The role of collaborative decision-making in product development can therefore be described as the task of collectively reaching an agreement on objectives and to use those objectives in order to reach a satisfying decision on performance tradeoffs. This is the basis for this research on collaborative decision-making in product development.

Research on Decision-Making

The application of Descriptive Decision Theory has largely been done in Operations research and Management Science, while Normative and Prescriptive Decision Theory has largely been applied in Engineering, Economics, and Mathematics. Collaborative decision-making, as a part of organisational decision-making, has been dealt with within different scientific areas. Decision analysis is common within normative and prescriptive approaches such as mathematics and engineering, observation of human decision-making activities is common in descriptive approaches such as management science, and decision-making as a group activity is common within behavioural science. [12]

In design science, the concept of decision-making is mostly focused towards the prescriptive models of decision-making in order to support designing. Theories of human behaviour are often limited to the level of “activities” conducted within product development and do not consider the aspect of fundamental decision-making behaviour.

Design Science, a multidisciplinary research area, includes human behaviour. It could therefore encompass decision-making literature developed within e.g. organisational science. In order to include knowledge from scientific disciplines other than those traditionally applied into the research area of design science, it is important to focus on the design of the research with the included research methods that support that multidisciplinary approach. After all, what distinguishes a researcher from a non-scientist is not what is being studied but how it is being studied [22].
An existing design research methodology has been adopted and used throughout this research with the intent to contribute with well-founded research results to both the industrial and the scientific community. The methodology, called DRM (Design Research Methodology) [23], outlines the necessary steps to take in order to produce research results that contribute to the system of knowledge of and for designing. Different research methods are chosen and used within each step to clarify objectives and find answers to the stated research questions being investigated at that time (see Figure 2).

In order to systematically describe the crucial aspects of the research in relation to the DRM, Maxwell’s model of research design is used [24]. That is because of its focus on research based on qualitative data (see Figure 3).
This model clarifies the Goals, Context (conceptual framework), Methods, Research Questions, and Validity of the research.

The Goals concerns the motivation of the research and is described in the “Problem Statement” and “Practical and Academic Relevance” in Chapter 1.

The context in which this research is to be conducted is described in Chapter 3, called “Frame of References” and also in the “Scientific Approach” below and in “Delimitations” in Chapter 1.

The Research Questions is stated in Chapter 1.

Methods used to investigate research questions in the case studies are described in “Methods for Collecting and Analysing Data” below.

Validity is about correctness of the research results and is discussed in “The Quality of the Research” below.

Scientific Approach

The researcher’s view of the “real world” affects the choices made about research approach and methods used throughout the research project. According to Abnor and Bjerke [25], there are three methodological approaches to choose from: the analytical, the systems, and the actors approach. These approaches are related to the two main paradigms in social science: the positivistic and the hermeneutic paradigm (see Figure 4).
The analytical approach aims at explaining the world as objectively as possible. The world is constituted by causal relations, i.e. cause and effect relations. Independent relations are sought, and Newton’s laws of physics are an example. The actors approach implies a view of the world as social constructions and knowledge is not objective. Social constructs are investigated and understood.

The systems approach was developed during the 1950s as a response to the difficulties in applying an analytical approach to social problems within a technical context. The research described in this licentiate thesis is based on the systems approach.

The systems approach can be used for open or closed systems. An open system interacts with its surroundings. In addition, a system can be divided into sub-systems, and the total sum of the system may differ from the sum of its sub-systems. This is due to the important relationships between the parts that impact the whole of the system. The systems approach aims at not only explaining but also understanding which forces cause an effect in the system. Decision-making in product development is often made by interacting actors in the system. This causes both quantitative and dynamic complexity. Decisions often include organisational and human factors as well as aspects of the technical systems. When focusing on the decision-making abilities of actors involved in product development, it is suitable to adopt a holistic view of organisational decision-making because of the complex relationships between decision and performance in the organisation. Therefore, in the attempt to improve decision-making abilities, this research focuses on the study of how decisions are made, not what is being decided. The systems approach emphasises a holistic view of the system in order to manage complexity, and is therefore suitable for the research of decision-making in a product development context.

The system of decision-making in product development is influenced by outside systems and forces, and is therefore considered to be an open system. These outside systems and forces are important motivators in the pursuit of decision-making skills in order to handle
complex decision situations. They also introduce an increased level of complexity to the system. Systems theory is a promising effort to deal with this complexity. There, an understanding of a system cannot be based on knowledge of the parts alone. The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity [26]. It is also important to see the processes of change for the system over time, rather than taking snapshots.

In order to make sense of collaborative decision-making, the dynamics of communication and information, as well as the relationships between the decision-making process and different influencing aspects, are important. In this research, the system of collaborative decision-making in an industrial context is understood through the use of systematic principles that reflect aspects of collaborative decision-making identified as important for decision-making success.

**Research Strategy - Case Studies**

Yin [27] describes different research strategies and their applicability to different research situations. The strategies are: *Experiment, Survey, Archival analysis, and Case study*. When studying a phenomenon within an organisation by stating how and why questions, case study is the preferred strategy. A case study is described as: “…an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.” [27] (p.13).

Generally, the case study approach was used as a strategy. That was because most of the collected data was qualitative and therefore suitable for qualitative research methods aiming to investigate current phenomena in their natural contexts [27] in order to better understand the dynamics of systems [28]. A case study copes with typical technical situations, and has the advantage of relying upon multiple sources of evidence.

In this research, decision-making can be seen as the phenomenon, while the product development project organisation can be considered the context. Interactions take place with stakeholders inside as well as outside of the project organisation. These are organisational and managerial studies appropriate for applying the case study strategy [27]. Merriam [28] also states that with a case study strategy it is possible to focus on interpretation and insight, rather than on the test of hypothesis.

However, the case study strategy is open to the incorrect interpretation of data or biased results when the researcher adds his/her own subjective judgement into the results. This requires the researcher to be conscious of these aspects and actively work to prevent them.
Methods for Collecting and Analysing Data

The typical methods for collecting data when applying a case study strategy include interviews and data gathering from documents. Interviews are used to gather data from participants and observers of the phenomenon of interest. Interviews can be conducted in a group setting or one-on-one and can have different degrees of structure [28].

The degrees of structure are often labelled structured, semi-structured, or open interview. The structured interview has predefined questions, while the open interview is a discussion between the interviewer and the interviewee. Often when research based on qualitative data is being conducted, semi-structured interview is the chosen method [28]. A semi-structured interview is prepared by stating a few questions that ensure the achievement of the overall goal of the interview. No detailed formulation or order of questions is prepared. Further, new questions are formulated by the interviewer based on data being analysed during the interview [28]. This approach aims at collecting as much data and insight as possible within the defined scope of the research.

The data collection made during this research was made through open interviews, semi-structured interviews, and analysis of companies’ documentation of decisions. Literature reviews were conducted throughout the research process within the fields of product development and decision-making in order to facilitate the identification of interview questions, as well as to provide a basis for the understanding of organisational decision-making when going into the case studies.

Yin [27] argues for the need of using analytical strategies when analysing data and presents several methods for analysing qualitative data. Categorisation [24, 27, 28], one example, includes the coding of data in order to rearrange data into categories to facilitate the comparison and development of theoretical concepts.

The Research Process

The research process was designed by connecting research methodology phases, research questions, and research methods. The connection between research questions and the research phases of the DRM can be seen in Figure 5. The methods chosen for investigating the research questions can be found in Table 1.

Even though the state-of-the-art and cases are placed within different phases and research question (Figure 5), the reality of answering the research questions has been much more complex. First of all, the research questions have changed over time, becoming much more refined in the end. Also, theories in literature have been studied throughout the research,
and conclusions from data in early case studies have been re-evaluated and updated in later stages. It has been an iterative process, just as Figure 1 describes.

![Figure 1](image.png)

**Figure 5. Connection between research questions and DRM phases.**

In the first research phase, called “Research clarification”, the state-of-the-art was compiled and Company X was studied in 2006, paralleled with a literature review. The conclusion was that decision-making is a skill that actors are unaware of in the efforts made by companies to improve the product development process. Company Y was studied in 2006-2007 in order to answer research question 2. The conclusion from trying to answer research question 2 was that a more in-depth investigation of decision-making in product development was needed in order to move closer to an answer to research Question 2. At the same time, research question 3 was stated.

In the Descriptive study, Company Z was studied in 2007-2008, and a literature review was made in order to answer research questions 2 and 3. The conclusion was that decision-making procedures, decision-making strategies, and structures are of great interest when trying to improve decision-making in product development.
Table 1. A summary of the research phases and case descriptions. A literature review is implied in all cases.

<table>
<thead>
<tr>
<th>Research phase</th>
<th>Design of case</th>
<th>No. of respondents (interviews)</th>
<th>Business focus</th>
<th>Unit of analysis</th>
<th>Data collection method</th>
<th>Data analysis</th>
<th>Data analysis</th>
<th>Research question</th>
</tr>
</thead>
<tbody>
<tr>
<td>Research clarification</td>
<td>State-of-the-art.</td>
<td>6 (7)</td>
<td>Company X, Electronics</td>
<td>Decision-making system</td>
<td>Interview, workshop, documentation</td>
<td>Categorizing (coding)</td>
<td>RQ1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multiple-case/holistic</td>
<td>9 (12)</td>
<td>Company Y, Mechatronics</td>
<td></td>
<td></td>
<td></td>
<td>RQ2</td>
<td></td>
</tr>
<tr>
<td>Descriptive phase</td>
<td>Single-case/ embedded</td>
<td>7 (8)</td>
<td>Company Z, Mechatronics</td>
<td>Single decision-making process</td>
<td>Interview, documentation</td>
<td>Categorizing (coding)</td>
<td>RQ2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RQ3</td>
<td></td>
</tr>
</tbody>
</table>

During the research journey, there was an attempt made to conduct a prescriptive phase in order to develop a prescriptive approach to project decision management. However, the author did not consider it well-founded enough in order to contribute to the knowledge of collaborative decision-making and its relation to performance. Therefore, the author decided to continue to conduct descriptive case studies in order to gain more well-founded knowledge of collaborative decision-making in an industrial context.

Apart from the case studies conducted, the connection to a real industrial problem has been important to clarify and continuously validate throughout the research process. To ensure the connection to an industrial problem, a discussion partner from a large international company in Sweden was obtained early on and continuously provided useful insights about decision-making in product development. Further, the author’s supervisor, based in a large international company, always provided interesting and useful insight about decision-making in product development.

The Quality of the Research

Determining the quality of the conducted research is not an easy task when the research is based on qualitative data [29]. This is especially true if the researcher uses a systems approach that means that knowledge developed is not general in the same sense as knowledge developed in an analytical approach [30]. However, in general, research results are measured using Validity and Reliability.

This research, carried out through case studies, is measured using the terms Validity and Reliability based on Merriam [28] and Yin [27]. Merriam describes two types of Validity:
internal and external. Yin discusses the issue of validity and how results may be generalised, as well as the issue of Reliability.

Validity

When case study is used to carry out research, two types of validity should be considered: internal and external [28]. Internal validity is defined as the reliability of the results regarding the studied reality. External validity, on the other hand, is defined as the reliability of the results regarding the applicability to other situations besides the one studied in the current case study.

The Research clarification phase within this research was based on several sources of data and information. Thus, it made the result (i.e. the problem statement and RQ₁ and RQ₂) more valid than if just one source had been used. However, the results of the second case study have proven to be applicable to the specific company studied at that precise moment in time. There is no definite proof that the results may be applied outside that specific context. However, Merriam [28] states that the external validity of case studies is often hard to prove. She also finds it possible to discuss why there is no reason that the results would not be applicable to other cases. The importance of providing detailed descriptions of the conducted case studies is therefore increased in order to illustrate the context in which results are valid. Yin [27] proposes that case study findings be compared to established theory in order to investigate the existence (or not) of support for the results.

Reliability

Reliability is the ability of a researcher to repeat the same studies made and to reach the same results and conclusions as the first researcher did. Reliability within the systems approach is focused on what the measurements can be used for, not how precise they were during the case study. Consequently, in contrast to the analytical approach, the systems approach does not consider reliability to be as important [25]. Merriam [28] explains how reliability becomes a troublesome quest when studying human behaviour that is dynamic, not static. However, Yin [27] proposes that reliability is possible to obtain if other researchers gain access to the same documentation and well-documented research procedures used by the first researcher.

This research has been carried out using methods such as interviews, project documentation, and workshops within an industrial context. Another researcher would be hard pressed to repeat the same research and obtain the same results due to changes in the context and access to the same documentation and situations.
On the other hand, if the research questions within this research were asked by another researcher and studied under the same conditions, the results could be similar in essence [31]. For example, how actors make decisions is not easily changed and could be observed under the same conditions and research question by different researchers and reach similar results.
This chapter introduces the theory used in this research in order to gather relevant data, analysis, and reflection on collaborative decision-making in product development activities. The chapter is divided into two sections: the process of developing products and decision-making in a product development context. The first section introduces theories of product development activities, product development performance, and how product development performance can be improved. The second section then introduces theories of decision-making, product development as decision-making, and collaborative decision-making. Finally, this chapter is the summary of the compiled state-of-the-art and serves as a starting-point and basis for the research.

A research question was posed to investigate what was needed in order to manage decision-making fundamentals, decision-making success, and the relation to the collaborative product development process:

RQ1 – What is decision management in collaborative product development?

This chapter summarises the state-of-the-art compiled in order to answer research question 1.

The Process of Developing Products

The process of developing products has become a central contributor to companies’ competitiveness. Since the mid-20th century, there have been vast efforts to try to support this process through theories, methodologies, and methods. These efforts have been aimed at supporting certain aspects of difficulties at that time. Examples include shortening lead-time and improving team integration. The interesting question is what aspects of the processes of developing products does product development literature consider important when aiming to increase the performance of the process? The following part of this section is aimed at clarifying that question.
There are generic definitions of the process, and the whole product development process can be defined as: “… the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product” [32] (p.2). In literature, the definition of product development [32] is often diverse. Examples include Complex Product and System Development (CoPS) [33], New Product Development (NPD) [34], Knowledge-Intense product development [11], Product Innovation [35], and Engineering Design [18]. Further, the definitions (along with the numerous methodologies and models of product development) describe different characteristics of the product development process. Systems Engineering (SE) [1], Concurrent Engineering (CE) [2], Integrated Product Development (IPD) [7], Dynamic Product Development (DPD) [36], and Stage-Gate [8] are examples, to mention a few. All of these models aim to support design activities in different ways. The evolution of these methodologies was described in the first chapter.

Models for design activities are mothered by a design theory, “…a design theory means a mental structure, adequately validated, representing a design process or a design object…” [37] (p.26).

The design theory consists of the mental model governed by a methodology, “A methodology can be defined, in a general sense, as a situation-adapted system of methods to solve a complex problem” [37] (p.26).

The methodology gathers the needed methods to develop a product: “…design methodology basically aims to provide a framework for supporting design activities such as problem definition, establishment of requirements, generation of solutions, evaluation of solutions, and decision-making” [37] (p.27).

Activities and decision-making in product development are often described as problem solving activities where a present state of the situations is described, as well as the future preferred state [38] (p.2). Goel [39] describes the nature of design problems (activities) by viewing them as a function of abstraction hierarchies. The abstraction hierarchies show how the nature of the output of product development activities change during the design process (see Figure 6). It shows how the focus of decision-making shifts from identifying people with different competencies in order to state the purpose of the future decisions to decisions about functions and properties of the artefact.

![Figure 6. Shifting characteristics of the product development process [39].](image-url)
All these activities are described on a methodological level and are typical for product development methodology literature. Product development literature that describes the specific aspects of importance within the methodology stages in more detail often focuses on specific decisions or aspects that need to be considered during that specific stage. Specific decisions are summarised, for example, by Krishnan and Ulrich [40], and all of them have been extensively researched by the product development research community. Krishnan and Ulrich [40] describe generic product development decisions made at three levels in the organisation: strategic, project management and operational. They divide the decisions into those made when setting up a project and those made during a project. When looking at the product strategy level, five generic decisions are made: (1) what is the market and product strategy to maximize probability of economic success?; (2) what portfolio of product opportunities will be pursued?; (3) what is the timing of product development projects?; (4) what assets (e.g. platforms), if any, will be shared across which products?; and, finally, (5) which technologies will be employed in the product(s)? When looking at a project management level, five other generic decisions are made: (1) what is the relative priority of development objectives?; (2) what is the planned timing and sequence of development activities?; (3) what are the major project milestones and planned prototypes?; (4) what will be the communication mechanisms among team members?; and, finally, (5) how will the project be monitored and controlled? Further, when looking at the operational activity level, eighteen generic decisions (divided into five categories) are made. Those categories are: Concept development, Supply chain design, Product design, Performance testing and validation, and Production ramp-up and launch [40].

In addition, examples of specific aspects considered important in product development literature are uncertainty [41], value [42], and decision structuring [12, 43].

Bras and Mistree [43] define the entities of a process to be hierarchical and are as follows:

- Process
  - Phases
    - Events (activities)
      - Tasks
    - Decisions

Tasks and decisions require the direct involvement of humans. Phases and events are accomplished by performing tasks and making decisions. The product development process itself is a task for the assigned team to perform. A task may involve different tasks, decisions, phases, and events. Tasks may or may not include decisions, e.g. routine work. [43]
The tasks and activities conducted during product development are increasingly dependent on access to accurate information, extraction, and exchange. Further, the decision makers need to identify and include different expertise and perspectives in order to make informed decisions. All this has made the product development process dependent on collaborative decision-making. [12]

Collaborative decision-making is not the study of one perspective, such as communication, synthesis, or decision analysis; rather, it is the study of them (and many more) as a whole. It is necessary to view decision-making as a whole (i.e. a system) in order to relate decision-making to product development performance.

What is product development performance?

What is product development performance? That question, as literature shows, is not easy to answer. We do know that it is a direct result of our decisions and choices during the product development process.

The characteristics of the development process originated from the design of machine elements. They have changed over time, due to the inclusion of other aspects of the process (e.g. communication, teamwork, and project management). The area of product development has grown to include many aspects of the process, and it has become hard to overlook. It is today a rather fragmented multidisciplinary research area. Horváth [44] (p.155) states: “Engineering design research shows a rather fragmented, if not a chaotic, picture.”

This, and the fact that industry does not use or even know of the research-based product development methods and theories [20], makes improvement of the process of developing products a complex task. Engineering design research tends to focus on specific aspects of the process or decisions in order to improve through the identification of, for example, success factors or specific procedures. Examples include [45-48]. Examples of more holistic studies of the process of developing products exist. However, they are often limited to the identification of generic success factors, and do not explicitly relate the factors to decision-making. [8, 49] are examples. Also, synthesises have been made of what specific aspects are considered and decisions made during product development in order to analyse what the content of product development methodology and methods should support. [40, 50] are two examples.

The role of performance aspects of organisational management have been considered important for a long time [51]. The difficulties in investigating performance in product development are discussed by Kerssens-van Drongelen et al. [52], who identified the aggravating characteristics of the performance measurement problem as follows:
• “accurately isolating the contribution of R&D to company performance from the other business activities”
• “A second problem with measuring the contribution of R&D to the company is that a part of the benefits it generates is hardly quantifiable”
• “A third issue is the problem of matching specific R&D inputs (in terms of money or man-hours) and intermediate outputs (research findings, new technologies, new materials, etc.) with final outcomes”
• “A fourth major measurement problem is the time lag between R&D efforts and their payoffs in the marketplace”
• “It is consequently considered to be difficult to compare and contrast two projects, as they will always be different”
• “The final problem is the acceptance of performance measurement in R&D”

The research area of performance in product development is a relatively new area of research. Consequently, there are few studies made focusing on performance in knowledge-intensive product development [53]. Further, the term performance is often used in product development literature without a clear definition [54]. Terminology, including performance, effectiveness, efficiency, and productivity, is misused and used in a confusing way [55]. There are exceptions, e.g. [56] and [57]. They provide a concept of performance which states that “Effectiveness” plus “Efficiency” equals “Performance”.

Effectiveness in product development is often closely connected to the levels of customer requirements and product development objectives that are met [58–60]. It is the matter of doing the right thing for the customers. Efficiency is closely related to the rapid creation of value and the resources spent [58, 60]. The thought is to spend as little resources in order to create a given output. O’Donnell and Duffy [54] use IDEF0 modelling in order to create a clear definition model of activity performance (see Figure 7).

![Figure 7. Effectiveness and efficiency model [54].](image-url)
The model is to be interpreted as follows: an organizational function, activity, or decision has input, output, a goal, and resources. If output is compared to goal, effectiveness is determined. If the relation between output and input is compared with used resources, efficiency is determined. However, both effectiveness and efficiency are influenced by uncertainty in decision-making. Further, uncertainty can affect the purpose of the decision (i.e. the created value).

Uncertainty in product development is the property of the business environment, and is the result of two forces: complexity and the rate of change [61]. Uncertainty consists of three elements according to Lawrence and Lorsch [62]: lack of clarity of information, general uncertainty of causal relationships between decisions and the corresponding results, and time span of feedback about the results of the decision. If people receive incomplete, uncertain, and wrong information during the decision-making process, they may perceive the environment as uncertain.

Specific sources of uncertainty in product development can be categorised in different ways. Souder and Moenaert [63] (p.485) states that “The four major sources of uncertainty are user needs, technological environments, competitive environments, and organizational resources. Reducing these uncertainties is the responsibility of the marketing and research and development (R&D) functions within the firm. Because these functions are reciprocally interdependent, their success in reducing uncertainty requires integration and collaboration between them.” Unger and Eppinger [64] categorise sources of uncertainty as follows: “Technical”, “Market”, “Schedule”, and “Financial”.

Uncertainty is often researched within product development through the identification of generic success factors of certain decisions or performance aspects in order to minimize uncertainty, thereby improving performance. A common approach to the minimisation of uncertainty in product development is to ensure that critical success factors are thought of and that reoccurring problems are proactively counteracted.

Improving the Process of Developing Products

Ulrich and Eppinger [65] (p.12) define the product development process as “…the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product”. The documentation of an organisation’s product development process may help in identifying opportunities for improvements [65].

Unger and Eppinger [64] also discuss the fact that although different companies’ product development processes are not uniform, they are used in similar ways to minimise
uncertainties and risks. The process of developing products often follows at least some form of the steps seen in Figure 8.

**Figure 8. A generic product development process [65].**

“The purpose of PDPs that include these steps is to provide a structure for managing the many uncertainties and risks that companies face. Segmenting the process into smaller actions is one way of controlling risks” [64] (p.2).

De Meyer et al. [66] and others stress the need to be aware of certain uncertainties in order to improve product development management [66, 67]. Unger and Eppinger [64] explain the inherited abilities of a structured process to reduce uncertainties through iterations, system integrations (e.g. prototypes), and reviews. Iterations are often used to address market uncertainties, while system integrations and reviews are used to minimise technical uncertainty.

The characteristics of different products influence the choice of process model (methodology) to be used in development organisations. Manufacturing companies tend to use a staged model, while software companies use a spiral one. The staged model uses narrow iteration within phases and rigid reviews, while the spiral model uses comprehensive iterations across phases and flexible reviews. The design and improvement of a product development process should be made through the identification of uncertainties and the prioritisation of risks. Uncertainties and risks should be assigned to iterations, cycles, reviews, or stages of the process. The planning of iterations and integration cycles should be done to address the risks. The last thing is to schedule key reviews. [64]

Clarkson and Eckert [50] (p.25) state that: “Design process should be tailored to the product under development, the competence of the design team and the aspirations of the users”. By arguing for the importance of trying to understand the design process from all points of view, from the individual designer’s problem-solving process to the continuous business development, it is possible to begin to affect the performance of the process. They go on to say that: “while these models all offer insight into the nature of design projects, they are far too general to help with project planning activities or to guide the daily decisions which must be made by design managers” [50] (p.25).

---

2 Product Development Processes
Early on, the development process was defined as a sequential “over-the-wall” process [68] where information was completed about the product before passing it on to the next phase in the process. Information is what enables the process and what product design methodology is based on. Depending on what category of information sought, the process can be divided into functions and phases.

The process can be described as “a process of gradually building up a body of information until it eventually provides a complete formula for manufacturing a new product” [69] (p.158).

As shown in the first chapter of this thesis, collaboration is a vital aspect of product development. It is also dependent on the ability to manage the information exchange between interfaces for upstream and downstream tasks, different sub-systems and different organisational functions. A substantial amount of information has to be coordinated and distributed in product development. The right piece of information should be available to all actors involved in real time [70]. An efficient organisation also has to understand the information-processing logic and its integration with its environment in order to make sufficient decisions.

The success of engineering companies is highly dependent on how well product design information is managed and communicated [71, 72]. Engineering designers use information from a variety of sources to undertake a wide range of design tasks. It has also been shown that engineers spend as much as 30-35% of their time searching for and accessing engineering design information [73, 74]. When engineers gather information, other people are often the most used information source. Without access to accurate, up-to-date information, engineers may make mistakes or misjudgements on aspects of the product design. Groups can sometimes make bad decisions by not considering all relevant information and not appraising the full range of options available [75]. It is also common that engineers prefer to use the information they already possess [76].

In summary, there are many different aspects of the process of designing products that can be used for improving the process. The difficult part of the work is to determine which aspect to choose when trying to improve the process. Wynn and Clarkson [77] (p.35) state that: “There is no silver bullet method which can be applied to achieve process improvement”. However, there have been promising attempts to establish more fundamental aspects of the development process in order to improve the process, i.e. decision-making. Herrmann and Schmidt [78] advocate a change in engineering thinking from a problem-solving to a decision-making approach. “We believe that this gap can be bridged by first understanding how we came to accept the view of engineering design as problem-solving and how that notion is reinforced by the very organisation structure of our manufacturing enterprises”. Herrmann and Schmidt [78] (p.1) propose to view product development as a decision production system. “Only a change in the view of the product development operations within a corporate environment will help clarify the role that
both engineering analysis and decision-making must play in effective product development”. Herrmann and Schmidt [78] also aim at improving the process of designing products by overcoming the barriers of communication in organisations, thus improving the information flow in order to facilitate decision-making. “A decision-maker gets some information, makes a decision, and consequently generates new information” [78] (p.6). The notion is to put all decision-makers on the same level, or on the same “virtual shop floor”.

Decision-Making in a Product Development Context

In Design Science, the theoretical body of knowledge of decision-making is a relatively new area. Decision-making is often an underlying and generically discussed process. In contrast to Design Science, Decision Science (Theory) has been developing for centuries.

Decision theory is an interdisciplinary research area aimed at understanding decision-making. It draws knowledge from mathematics, psychology, economics and other areas in order to better understand how to produce satisfactory outcomes under certain conditions [79].

What is a decision and decision-making?

The definition of “decision” is “to cut”. It is what you will and will not do (i.e. what to include and to cut out in order to design a satisfactory outcome) [16, 80]. A decision is commitment to a course of action and the irreversible commitment of resources [81-83].

On the other hand, there are three distinct different branches of scientific decision-making theories: the “Normative”, the “Descriptive”, and the “Prescriptive”.

“Normative” decision-making researchers would state that decision-making is the calculation of subjective value, i.e. utility. It means that, for example, the subjective value of money decreases when the amount of money increases. The normative approach investigates how to decide with logical consistency [79].

“Everyone wants good rather than bad, more rather than less – the question is how we get there. The only thing you can control is the decision and how you go about making that decision. That is the key” [84] in [79] (p.46).

The “Descriptive” theory aims at describing How and Why people decide. Here, Simon [13] was the first to criticise the normative approach for overestimating human decision-making capabilities. Simon stated that people do not act fully rationally when making decisions, but have cognitive limitations which he described as “Bounded rationality”.

39
These cognitive limitations are seen by normative theorists as systematic biases, while descriptive theorists view them as human cognitive errors. Bounded rationality is not optimization or irrationality [85]. Simon [13] argues that decision-making is about what he calls “Satisficing” rather than optimising, and he outlines the decision-making process as “Intelligence”, “Design”, and “Choice”. Intelligence is the search for understanding the problem, design is the development of alternatives, and choice is the analysis of alternatives and choice of implementation. The decision-making process is seen by Marsh [82] as “guesses about future consequences” and “guesses of sentiments of these consequences”.

The more pragmatic approach to decision-making, called “Prescriptive” decision theory, embraces “Bounded rationality.” It would describe decision-making as a process of identifying the need for a decision, defining the problem, specifying the goal and objective, developing alternatives, evaluating those alternatives, and making the decision. This procedural type of decision-making is often referred to as “the Canonical model” [79]. This decision model can be broken down and extended. Yates [16] does so, describing the decision-making process as: need, mode, investment, options, possibilities, judgment, value, tradeoffs, acceptability, and implementation.

The “Prescriptive” theory is mainly considered with “Decision analysis,” which aims at increasing insight and creativity in decision-making. Keeney [86] (p.821), states that: “decision analysis will not solve a decision problem, nor is it intended to. Its purpose is to produce insight and promote creativity to help decision makers make better decisions.” Prescriptive decision-making theory is concerned with the application of normative and descriptive decision theory in “real” situations.

What is a good decision?

Tang [79] (p.44), states that “There is no real consensus on what a good decision is.” However, there is some consensus within the three branches of decision theories.

In “Normative” theory, the outcome is not considered to be an evaluative factor to measure. High decision quality is achieved by following rigid rules and fulfilling axioms. According to Howard [84], we can control the decision-making process but not the result or outcome. It is however easier to direct the results than the outcome. The result is the implementation of the decided actions and the resources committed, while the outcome is influenced by natural variation and other influencing forces we cannot oversee or control. Therefore, the outcome is not an appropriate evaluative factor in decision quality [38].

In the “Descriptive” theory, aspects such as difficulty, missed opportunities, and good results are important factors of decision quality [16]. Nutt [87] developed criteria to evaluate
decision quality by considering three measures: measure of “decision value” (impact, merit, and satisfaction), measure of “development time” (decision cycle time, and evaluation), and measure of “decision use” (initial adoption, sustained adoption, and full adoption). By evaluating decisions according to these measures, Nutt discovered that half of all decisions fail [87].

In the more pragmatic “Prescriptive” theory, the measure of the decision quality is exemplified by Howard [84], who lists six criteria for achieving a high quality decision: (1) a committed decision-maker, (2) the right frame, (3) the right alternatives, (4) the right information, (5) clear preferences, and (6) the right decision procedures. The fulfilment of the last criteria (the right decision procedures) is based on the fulfilment of normative axioms and criteria [79].

**Decision-Making in Product Development Literature**

Kennedy [88] provides an example of corporate capabilities for development excellence that is divided into three categories: Process, Organisation, and Culture. Decision-making is placed within the Culture category, where it should be supported by entities within the Process and the Organisation categories. Bakka et al. [89] divide an organisation into the same three categories. Although they place decision-making within the Process category, they find decision-making tightly connected to the other categories as well. In this research, the process angle is chosen in order to relate to the product development process. Nonetheless, it includes aspects within Organisation and Culture as well. Longueville [90] states that the decision-making process is often seen by people within product development as related to the organisation, the processes, a decision structure, and the result (the product).

Regarding the process, the product development process model makes the process explicit, allowing everyone in the development team to understand decision rational and preventing moving ahead with unsupported decisions [65] (p.7).

Product development process models are models of how to make decisions in a sequential manner in order to decide the design of a product, how it should be manufactured, and sold. If we investigate the actual decision-making beneath the surface of the product development process model, we find patterns of leaps, loops, and cycles of decision-making processes [91] that are not often explicit in the product development process model. There are examples of models that illustrate some iteration in the process, e.g. [18] and do not (and do not intend to) reflect actual decision-making behaviour. These models are often activity-based and show the generic sequence of activities that need to be carried out in order to develop, produce, and sell a product.
These process models used today (Integrated Product Development is one example) are based on the thought of a linear development procedure that originated in the mid-1940s. This linear approach is somewhat appropriate for product development when the generic product development process has shifting characteristics when moving forward in the process. That shift, from a need in the market to a product on the market, can be described as different phases with the specific characteristics. Further, product development activities within the phases are to be executed in parallel in order to shorten the lead-time of projects. This has led to a decrease in the flexibility used for managing uncertainties in the process [92].

The uncertainty in product development activities, tasks, and decisions is ever present. Situations not guided by the models always arise during product development, and they need to be handled with other means. How these situations are handled depends on the knowledge, information, and methods available.

Decisions can be divided into categories depending on the nature of the decision. One perspective is activities in the product development process during execution. Krishnan and Ullrich’s “decision framework” includes approximately 30 major decisions at a project level, divided into categories [40]. They also found that although different organizations make different decisions during product development, all decisions revolve around groups of common issues. The groups include product concept, architecture, configuration procurement, and project schedule [93].

Recently emerged research, e.g. López-Mesa and Chakrabarti [48], focuses on how engineering designers develop knowledge and make decisions during product development. In other words, it focuses on synthesis, a part of the decision-making process of engineering designers. It describes how designers use a certain decision-making strategy when synthesising. There are many interesting questions about the designer’s individual strategy: is it a good strategy? Can it be altered? Should it be altered? Nonetheless, the research described in this thesis will not try to answer those questions. Instead, it will examine how groups of people make decisions together and how decision-making can be supported throughout the development process and involves more than synthesis.

Hansen [94] proposed a mindset for engineering design decision-making based on the results of Ahmed [95]. The mindset is intended to form a sound basis for the engineering designer’s understanding of decision-making, and explain all relevant phenomena related to design decision-making. Hansen and Andreasen [96] presented a model of an evaluation and decision-making activity called “The decision node”. It explains a decision episode of an engineering designer in a generic way. A second model, called “The decision map”, was also introduced. It explains what is synthesised during the design process. It shows the three artefacts designed during a product development project: the product, the life phase systems,
and the meetings between the product, operator, and the life phase system. A third model, called “The decision score”, explains the five dimensions that the consequences of design decisions impact: the use process, project tractability, the product, the business, and the product life cycle. The mindset proposed by Hansen and Andreasen aims at supporting design decision-making. Further, it has common objects of interest with project management decision-making, such as the progression of the project, specifications, the product life cycle, and business.

Gidel et al. [97] provide a mindset for increased problem solving capacities in complex decision situations when planning within a project. The purpose of the mindset is to organise the decision-making process in an acceptable way in order to make increasingly effective decisions. By looking at influencing factors, and which could be managed, Gidel et al. present a framework which could create a favourable context for effective decision-making in all levels of the design process. Gidel et al. draw inspiration from quality principles and systematic modelling of decision-making processes in design. The quality principles used are: controlled decision-making (a logical and intuitive approach), staff involvement (communication), and prevention (of unwanted consequences). The modelling of decision-making processes in design contributes to the mindset by providing the clarification and classification of influencing factors in order to amplify the decision-making capacities. However, the model is aimed at setting up and planning projects on a generic level and does not support the clarification of unplanned decision situations on a practical level.

All these approaches to product development processes, phases, activities, tasks, and decisions are based on a rational view of human decision-making. Further, they argue that rationality promotes good decisions. The question is if some things are overlooked if the view of rational decision-making behaviour is the basis for our efforts to improve product development processes.

**Different Views of Decision-Making in Product Development**

Let us assume that we regard decision-making as a rational human activity. What would be the benefits and downsides?

The appeal of viewing decision-making as a rational activity is understandable and, in certain cases, very useful for facilitating decision-making activities [16, 98]. It promotes a structured and procedural approach to decision-making and may support an informed decision. The procedural approach facilitates answering what alternatives are available, what consequences are likely related to the alternatives (expectations), how valuable the alternatives are in relation to the stated goals of the decision (preferences), and how we are
going to decide between the alternatives (decision rules). This approach also depends on
guesses of future states, and how the decision maker would feel about the future states. That
means that when evaluating alternatives, these two often hidden guesses will influence the
decision-making process. A rational description of the decision is often a retrospective
explanation rather than an actual description of human decision-making behaviour. [99]

Uncertainty of consequences impacts the ability to treat decision-making as a rational
activity. Uncertainty in product development is always present at some level. Decision-
makers may be unaware of driving forces and therefore see the decision as uncertain. The
study of situations with integral uncertainty within a rational approach is often called
“Decision-making under risk” [100].

Also, the rational approach is influenced by assumptions. These assumptions are, for
example, assumptions of information about current state of the situation and involved
actors, assumptions of preferences about consequences and alternatives, and assumptions of
decision rules. There are approaches developed to include control of assumptions in rational
approaches. However, they often only consider one aspect of assumptions at a time. For
example, multi-actor theories do not include assumptions of information (limited
knowledge). [99]

The theories of the decision-making process began with the normative theories about the
rational behaviour of people. Those normative theories are encapsulated in “The Economic
Man”, created by Simon. The normative decision-making model may be viewed as
unrealistic. However, it is better viewed as a basis for discussion about the extreme of “ideal
decision-making” (see Figure 9) [89]. The normative model of decision-making is closely
related to prescriptive models of decision-making, which often strive to support an ideal
decision-making process. However, prescriptive theory that advocates a rational approach
often falls short in prescribing how to develop the alternatives before evaluating them [79].
It is the model of ideal decision-making which has led to the efforts to describe empirical decision-making as a sequential process of decision-making steps and activities that impact our way of thinking of decision-making even today (e.g. product development methodologies, see Figure 10).
Simon [13] was the first author who questioned the normative model of decision-making. He presented the “Administrative Man,” which was based on empirical decision-making behaviour patterns. The key to his model is the thought that rationality is a variable in decision-making that can be investigated in decision-making situations in order to determine the level of rationality. Simon describes the properties of the economic man (summarised in [89]):

- Rationality is bounded to a person’s frame of reference
- The goal is to reach a “Satisficing”, not an optimal solution
- Routines are sought after and satisfying, but may impact decisions negatively
- Daily work often gets the upper hand and gets in the way of planning

Simon [13] states that every decision made in an organisation involves elements of two kinds called “factual” and “value”. The factual element can be empirically proven right or wrong, but the value (ethical) element cannot. The factual element is the beliefs of the administrative man regarding how the world really is, true or false. This is important in
product development, where fact-based decisions are thought to be important to the success of the organisation. About product development, Simon states the difficulty as: “to synthesise crucial information for decisions when it originates in different and remote sources” [13] (p.55).

The importance of the information and communication aspect in product development decision-making in relation to synthesising is thereby highlighted and presented as a key aspect. However, this aspect is not easily managed when there are several people involved. Therefore, it is interesting within product development to analyse descriptive models of this aspect in order to understand empirical decision-making, as well as prescriptive rational models in order to investigate the support for decision-making.

Descriptive models of decision-making in product development are not common but examples do exist, e.g. [101, 102]. Prescriptive models, more common, are often presented as decision stages or aspects of consideration in a specific decision situation in the product development process. These models present crucial information categories to gather and analyse in order to resolve a specific decision problem (e.g. how to choose a design with regard to holistic customer requirements [45]).

Within organisational studies of human decision-making, there are other uncertainties identified and means to minimize the uncertainties. Lipshitz and Strauss [41], for example, found that humans conceptualise and distinguish between three different uncertainties: inadequate understanding, incomplete information, and undifferentiated alternatives. It was also found that people use five different strategies when coping with these uncertainties: reducing uncertainty, assumption-based reasoning, weighing pros and cons of competing alternatives, suppressing uncertainty, and forestalling. These strategies are how people respond to uncertainty when making decisions in a naturalistic setting.

These pros and cons of viewing decision-making as a rational activity need to be considered in order to understand decision-making in product development activities. One way of viewing decision-making is bounded rationality and striving for informed decisions [99]. The understanding of decision-making in product development must also be based in a collaborative context, as most important decisions are made collaboratively.

**Collaborative Decision-Making in Product Development**

In product development processes, most decisions are made in cooperation with others, be they shared decisions or decisions with input from others. Jankovic [12] (p.26) states: “In New Product and Process Development processes, the collaborative decision-making is the most frequent
decision-making process. Therefore, this is an important issue in New Product and Process Development.”

Jankovic’s definition of collaborative decision is adopted and used in this thesis:

“Collaborative decision-making is a collective decision-making where different actors have different and often conflicting objectives in the decision-making process.”

(Jankovic, 2006)

The advantages and disadvantages of collaborative decision-making constitute an interesting research area of decision-making. Jankovic [12] describes the advantages and disadvantages, and they are summarised in Table 2.

Table 2. Advantages and disadvantages of collaborative decision-making.

<table>
<thead>
<tr>
<th>Advantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collaborative decision-making enables synergy effects.</td>
</tr>
<tr>
<td>Collaborative decision-making involves the consideration of different aspects, which may lead to fewer uncertainties.</td>
</tr>
<tr>
<td>Every actor has different information concerning different aspects of the same problem, enabling a better-informed decision.</td>
</tr>
<tr>
<td>Collaborative decision-making enables an increased amount of developed alternatives.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every decision maker has his own preferences concerning the decision, and they influence the decision.</td>
</tr>
<tr>
<td>Decision makers have different frames of references and different information, and therefore have different value judgements.</td>
</tr>
<tr>
<td>Actors may have different objectives for the decision-making process. These objectives are important to consider, or the project may suffer.</td>
</tr>
<tr>
<td>As collaborative decision-making is multi-actor decision-making, the problem of post-control is an important issue. Decisions made need to be analysed regarding the coherence to development situations.</td>
</tr>
</tbody>
</table>
Ullman [103] describes the elements for collaborative decision-making success as: building a shared understanding, adopting a front loaded strategy, managing decision-making styles, developing a team strategy, avoiding group-think, achieving buy-in and accountability, and obtaining the best information from stakeholders. The element of a shared understanding has been explored by other researchers. For example, Mohammed and Ringseis [104] (p.310) state that: “Results revealed that unanimity decision rule groups achieved more cognitive consensus than majority rule groups. In addition, group members inquiring concerning the reasons underlying others’ decision preferences, accepting others’ viewpoints as legitimate, and incorporating others’ perspectives into their own interpretation of the issues was positively related to arriving at a greater degree of cognitive consensus.”

In order to create a basis for the understanding of collaborative decision-making in product development, Jankovic [12] uses the systems approach to model the collaborative decision-making system in a product development environment at a large French automobile manufacturer (see Figure 11).

![Figure 11. Collaborative decision-making system [12].](image-url)
According to Jankovic [12], collaborative decision-making can be viewed as a complex phenomenon due to the following:

- Involved actors have different objectives, knowledge, and preferences concerning the decision.
- The objective of the collaborative decision differs from the individual objectives of the involved actors.
- Decision criteria differ between actors with different objectives.
- Interrelations between operational processes influence and are influenced by one another’s input, output, and decisions.
- The input, output, and decisions depend on the ever-changing operational processes, introducing unpredictability into the collaborative decision-making process.

Ullman [103] gives further examples of why collaborative decision-making can be viewed as a complex phenomenon. They are the following:

- The information is uncertain.
- All actors have different interpretations of the information.
- Hard to control the process.
- Unclear goals and procedures.
- Hard to clarify risks.
- Hard to manage alternative and criteria evolution.
- Hard to achieve buy-in from all actors involved.

Therefore, it is interesting to discuss the following aspects of collaborative decision-making in a product development context: objectives, Uncertainty, Preferences, Alternatives, Criteria, Structures, Processes, Communication, and Environment.

Objectives in a development project can be defined at a strategic, tactical or operational level, and depend on their acceptance by actors influencing the outcome of the decision [105]. Collaborative decision-making objectives are the results of human activities, and are therefore influenced by actors’ preferences and behaviour. An actor’s performance is a measure of the amount of resources spent and the degree of fulfilment of the stated objectives. [12]

In many systems engineering activities, the requirements engineering process is viewed as a central part in order to facilitate an effective and efficient system. There is a strong link between requirement specification and goal modelling. Goal-oriented approaches explicitly link business goals and objectives with system components. These approaches can also be used to explore the boundaries of the system development project [106]. Jankovic [12]
describes the flow down of objectives in Figure 11. However, even if clear objectives exist, there still remains uncertainty in knowledge and information due to the complex nature of product development organisations and activities.

Uncertainty of information can be caused by cognitive limitations, organisational uncertainties (dependencies on other’s actions), and variations in the environment and measurement [103]. Also, a constraint that often impacts on the level of knowledge and uncertainty in information in a negative way is the limited amount of time [99]. March [99] describes the constraints on information as problems of attention, memory, comprehension, and communication. In bounded rationality, time is a limited resource that corresponds to a product development context. It also constitutes a constraint on the search and attention to information. There are limits to the amount of information individuals and organisations are able to store. An even more problematic issue is the identification and retrieval of relevant information when searching for information during decision-making [99]. In product development organisations, information stored by one stakeholder is often not easy to retrieve by another stakeholder. March [99] describes how an actor has limited cognitive abilities to comprehend connections between information and, therefore, has limited abilities to organise, summarise and use information that could be useful to make a decision. In collaborative decision-making, the involvement of stakeholders in the decision-making process facilitates informed decisions by incorporating more information and viewpoints than one actor alone. Finally, March [99] describes how the ability to communicate the decision and transfer the understanding is limited, even if the necessary information is available to an actor and the level of knowledge is sufficient to make a well-informed decision. Misunderstandings and inference often render the decision less effective when implemented.

Preferences: Today, product development has a great deal to do with identifying customer needs, wants, and wishes. However, we seldom discuss the needs, wants, and wishes of the group of people involved in the process of developing the product itself. This is because many decisions are considered to be made based on objective facts. What is interesting is that actors’ individual and shared preferences play a major role in collaborative decision-making. March [99] (p.189) describes how: “In practice, decision makers take an active role in constructing and shaping their preferences. They make decisions by considering their effect on future preferences.” In this research work, an adaptation of Jankovic’s definition of preferences of actors in collaborative decision-making is used. Jankovic [12] describes how an actor's preference influences the decision context, as well as competence, uncertainty, and decision importance.

“Preference is preferable solutions of one actor in a specific decision context.”

(Adaptation of Jankovic, 2006)
Alternative generation is often sacrificed due to limited resources, whether it is alternative concepts of the product or alternatives to smaller decisions. In an ideal world, relevant alternatives would be developed timely in the decision-making process. In reality, however, they are often developed when time is running out. The importance of developing alternatives in product development in order to produce high quality solutions, as well as in decision-making in general, has strong evidence, e.g. [107]. There are different types of alternatives: a single alternative, either-or alternatives, and multiple alternatives. [103]

A quote of Emile-Auguste Chartier illustrates the importance of alternatives: “There is nothing more dangerous than an idea, when it is held by a man who has only one...”.

Criteria define and clarify issues, and are the standards against which one evaluates features and attributes of alternatives. Some criteria concern resources or physical attributes that are easy to measure. However, there are also some criteria that need to be evaluated using “softer” measures. Criteria often co-evolve with alternatives and need to be refined during the decision-making process. Criteria in collaborative decision-making are hard to manage when different actors have different preferences and objectives [103]. Ullman’s [103] definition of criteria is adopted and used in this thesis.

\[\text{criteria} = \text{feature} + \text{target} + \text{importance}\].

(Ullman, 2006)

A feature is defined as an attribute or parameter, and is a characteristic of the considered alternative. Target is the stated or unstated goal for the feature, and alternatives are evaluated as to what degree they meet that goal. Finally, importance is considered from a specific viewpoint, and states the significance of the criterion in order to resolve the issue [103].

Structures of decisions in organisations are often described as either information structures (including processes and the organisational structure [65]), group structures (responsibilities and authorities [108]), or product structures, [18]. However, the definition of decision structures in this research work is the collaborative decision-making system of Jankovic in Figure 11. It will be further developed during this research work.

Processes of collaborative decision-making in product development are treated on different levels. The product development models, representing methodologies, often include phases, activities, tasks, and decision activities. [5, 7, 18] The activities and tasks are often managed through Gant diagrams where related resources are included. However, the fundamental decision-making process (canonical model) is often implicit and not planned or prepared. In this research work, an adaptation of Jankovic’s definition of process is used.
Communication is crucial to the success of collaborative decision-making and product development. Information needs to be developed, exchanged, and communicated in order to create a shared common understanding of the problem [103]. The decision made also needs to be communicated and understood by stakeholders in order to facilitate a successful acceptability and implementation of the decision [16]. Communication is fundamental for human beings, but it is also difficult when many actors are involved in a decision. If four actors are communicating with one another, and a fifth is introduced, the number of communication links is increased from six to ten, almost double the amount. In product development projects today there might be in extreme cases over 100 persons contributing to a single decision [109]. Ullman [103] provides a model of stakeholders within development projects that includes team, stakeholders, outside experts, and decision manager.

Environments in product development, generally speaking, can be categorised into three generic organisational levels: strategic, tactical, and operational. There are actors and groups of actors at each of these levels who are responsible and authorised to make specific decisions. These levels provide a meaningful way by which organisational decision-making can be approached. It represents one way we can categorise organisational decision-making. According to Jankovic [12], the environment in product development organisations can be divided into decision, project, and enterprise environments. These three environments consist of contexts and actors which play certain roles in the organisational system. In this research, decision and project environment are studied. Jankovic finds that the collaborative decision context is influenced by uncertainty, decision importance, and risk. However, as shown in the section “Different Views of Decision-Making in Product Development,” there are further influences to consider and manage.

Decision Management and Decision Support in Product Development

According to Fitzgerald [110], state-of-the-art decision-making includes more than just problem-solving. It comprehends rationality; rapid and easy access to relevant, high quality data; intuition; inner tranquillity; global concerns; inclusion of all stakeholders; and appreciation. Fitzgerald thereby highlights the complexity in decision-making.

Jankovic [12] proposes a framework for management and support of collaborative decision-making processes in product development organisations. The results from the study provide a means to manage global progress monitoring, process control, and launch corrective
actions. At the same time, it offers support for the structuring of collaborative decision-making and the identification of necessary elements and information. The developed framework does support structuring, monitoring, and to some extent, the control of the overall formal decision-making process. However, the framework does not support the framing and design of decisions or decision strategies in decision-making activities.

During a product development project, there are many decisions made, whether actors follow a product development process, a traditional business process or a stage-gate process. All of these processes are characterized by the production of information and punctuated by decisions, and it is the quality of the decisions that determines the time, cost and quality of the result. Nutt [111] found that half of the decisions in organisations fail. They are the sorts of decisions managers face every day (e.g. about new products, staffing, marketing, planning, construction, and customer service) [111].

Ullman [103] (p.36) defines “Decision management” as: “. . . determining what to do next with the available information, making the best possible choice with known risk as a transparent part of the process, and documenting the result for distribution and reuse.”

The crucial points in the definition according to Ullman are:

- “Best possible” choice, which is the goal of the whole decision-making process. There are never correct answers, only satisfactory ones.
- What to do next, which is crucial to analyze to make the best possible decision in the end.
- Available information, which is often partial, uncertain, biased, or subject to change and can also be dispersed over time.
- Known risk, which is vital to analyze to make a decision so that the decision maker can weigh the alternatives against the risk.
- A transparent part, as the decision management should support the overall work organisation.
- Documenting the result, so it can be distributed to dispersed teams or team members for the purpose of reusing information and the process itself.

Yates [16] (p.4) defines “Decision management” as encompassing: “. . . all the things that every manager does, consciously or otherwise, that damage or improve the quality of the company’s decisions, and thereby the company’s welfare.” According to Yates, although there are numerous ways for managers to influence the decision-making of people in their organisation, those ways can be categorised into the following four action types:

1. Influencing specific decisions
   a. Deciding personally
   b. Participating in decision groups
c. Affecting other’s decision deliberations

2. Supervising decision routines
3. Shaping decision practices
4. Providing decision resources

Yates [16] also describes the four drivers of poor decision management:

1. Failure to recognise responsibility of decision management.
2. Vague appreciation for decision problems and processes.
3. Ignorance of natural decision-making.
4. Limited awareness of useful principles.

Hammond et al. [98] describe the eight keys to effective decision-making:

1. Work on the right decision problem. The way a problem is framed from the start effects the outcome to a large extent.
2. Specify the objectives. Consider the interests, values, concerns, fears, and aspirations in relation to the goal.
3. Create imaginative alternatives. The decision cannot be better than the best alternative.
4. Understand the consequences. Assess the consequences of alternatives in a frank way.
5. Grapple with the tradeoffs. Choosing intelligently from less than perfect alternatives demands the comparison of competing objectives.
6. Clarify the uncertainties. Confront uncertainty and judge the possibility of different outcomes and their impacts.
7. Think hard about the risk tolerance. A conscious awareness of the acceptance level of risk is necessary.
8. Consider linked decisions. Isolate and resolve near-term issues while gathering information needed to resolve issues that will arise later.

What Ullman [103], Yates [16], and Hammond et al. [98] have in common is not hard to identify. They all use the prescriptive canonical model to facilitate a structured approach to decision-making activities. These all try to account for bounded rationality, objectives, evaluation, preferences, alternatives, uncertainty, and implementation, which to some extent could be used in order to improve decision-making capabilities of groups of actors in product development.

In the product development literature, we find methods and tools to support decision-making on different levels in the product development organisation. According to VDI-guideline 2221 [112], the engineer (operational level) has at his/her disposal different
methods to support the clarification and structuring of the design tasks within a range of design stages in order to make decisions. Examples of design methods are: Brainstorming, Cost-benefit analysis, Use-value analysis, Decision-tree analysis, and the Decision criteria matrix. The project manager (project level) has mostly methods for structuring activities and the management of project stakeholders, resources, and costs. Examples include Stage-gate process [8], Deficiency Report (resource management and analysis) [113], Enterprise Resource Planning (cross-functional resource management) [114], Interface chart (stakeholder analysis and planning) [115], and Recovery-Wave Planning (incremental project planning). There are exceptions to the generic methods, such as the Critical Chain Concept which focuses on project performance and decision-making [116]. The problem is that the project manager’s task is complex, and existing methods and tools are often too generic in nature [117].

Another approach to decision management is the use of clear and simple decision-making tactics. This has proven to be a common denominator of fast and effective decision-making [85, 118]. Eisenhardt [118] (p.4) states that: “Overall, fast decision makers use simple, yet powerful tactics to accelerate choices.” The thought is that by using a small number of tactics, the implication is fast and good enough decisions (see Table 3).

Table 3. Decision-making tactics [118].

<table>
<thead>
<tr>
<th>Fast and good enough decisions</th>
<th>Implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Track real time information on firm operations and the competitive environment</td>
<td>Act as a warning system to spot problems and opportunities early on. Builds a deep, intuitive grasp of the business.</td>
</tr>
<tr>
<td>Build multiple, simultaneous alternatives</td>
<td>Permits quick, comparative analysis. Bolsters confidence that the best alternative have been considered. Addis fallback position.</td>
</tr>
<tr>
<td>Seek the advice of experienced counsellors</td>
<td>Emphasizes advice from the most useful managers. Provides a safe forum to experiment with ideas and options. Boosts confidence in choice.</td>
</tr>
<tr>
<td>Use “consensus with qualification” to resolve conflicts</td>
<td>Offers proactive conflict resolution that recognizes its inevitability in many situations. Is a popular approach that balances managers’ desires to be heard with the need to make a choice.</td>
</tr>
<tr>
<td>Integrate the decision with other decisions and tactics</td>
<td>“Actively” copes with the stress of choice when information is poor and stakes are high. Signals possible mismatches with other decisions and tactics in the future.</td>
</tr>
</tbody>
</table>
Reflections on the Theory

The process of developing products is a major contributor to the overall competitiveness of companies. Therefore, there is a need for continuously improving the process. Product development methodologies and models are the usual approach to managing the product development organisation, process, activities, tasks, and decision-making. The models are based on a linear, normative approach to decision-making, and support decision-making on a high generic level. Methods used in order to support decision-making, e.g. QFD, FTA, only support specific tasks in the product development process (e.g. transfer market needs to product functions, or manage product requirement). There is often no structured approach described in order to support decision-making on a generic fundamental decision-making level (what strategies actors use to make decisions). There are exceptions that focus on specific decision activities. Hansen and Andreasen [96], for example, propose a mindset for engineering designers’ decision-making (i.e. synthesis and choice of alternatives). However, if the system is expanded to include not only design decisions made by one engineering designer, it means that there may be a lack of support of fundamental aspects of decision-making.

The theoretical review reveals that there is little written about these aspects as a whole. Decision management is often based on prescriptive models of decision-making. These approaches often relate decision-making to different decision performance aspects (e.g. reaching consensus or satisfaction). The models of decision management do not relate to product development process performance. Product development methodology is often the basis for process improvements and describes the product development process from different views. The product lifecycle, concurrent engineering, design phases, or engineering phases are examples. When relating product development processes to decision-making and performance, there are several aspects of particular interest. They include objectives, uncertainty, preferences, alternatives, criteria, decision-making structures and processes, communication, and decision environment.

The approach in this research is to view decision-making from a fundamental level and investigate the implications it has on process improvement efforts. The aspect of what decision-making success is and how to measure the success in order to improve decision-making is an important part of this research. Further, the relationship between decision-making success and product development process success is vital to clarify in order to create a decision-making system within a product development context.

The product development context is multiple and demands a consciousness of what context decisions are made in. Uncertainty in knowledge impacts the way actors make decisions and ranges from routine to strategy (see Figure 12).
Decisions may include ingredients from strategic, tactical, and operational levels which have different objectives with the decisions and need to be considered in efforts to improve the decision-making process (see Figure 13). This means that decisions need to be considered as a whole within the organisation, and puts great demand on communication and information.

The inclusion of different organisational levels in decisions also means that the planning of decision-making activities needs to be considered as a whole in the organisation. This is because different levels consider plans to have different roles and purposes, Figure 14.
The inclusion of actors from different levels and departments in the organisation places great demands on information and communication in collaborative decision-making. Information and communication become key aspects of collaborative decision-making and can be considered enablers. Communicated information enables a shared understanding of decision issues and increases the probability of a good enough decision. The shared understanding is also directly impacted by objectives, uncertainty, preferences, and decision criteria. Further, decision structures, processes, and environment also affect the output from decision activities.

Simple and few guiding rules and a less-is-more approach to information may be preferred if a decrease in development time is the ultimate goal. This leads to the thought of a less structured and more flexible approach to decision-making. And this approach stands in contrast to structured approaches, like the stage gate [8], which promotes the structured, planned, and sequential execution of formal decision activities based on large amounts of detailed information. However, if the goal of decision-making instead is an increased number of informed decisions, decision criteria other than time must be the focus of decision activities and may benefit from structured approaches to decision-making.

The performance of decision-making and its relation to the product development process performance are often not clear in literature, introducing ambiguity. Decision-making performance may be linked to an uncertainty aspect (for example, the increased amount of alternatives decreases the risk of an unsatisfactory solution to the problem). However, it does not specify in what way decision-making is improved. Do an increased number of alternatives imply the use of more resources, less communication, less information, an increased level of shared preferences, an increased ability to analyze consequences, or choosing better criteria for the evaluation of alternatives? What are the benefits and
downsides (tradeoffs) to transferring resources to that specific part of the decision-making process?

There is no silver bullet for improving the process of developing products, and this needs to be considered in relation to the specific situation of different organisations. However, there is a need to be able to relate improvement efforts to a current state of the organisation and a future state. Ultimately, decision-making is the common denominator of all progress in a product development process. In order to improve the process, a clear understanding of the relation between decision-making and process performance is needed.
Research questions two and three were posed and investigated during this research work. The goal was to investigate what effective and efficient decision-making in product development is. The two questions involved a literature review and a case study of two, respectively one, companies’ product development organisations. The case studies are presented in the following sub-section, together with the results and the conclusions.

Research Clarification – Case Study in Company X & Y

According to Blessing and Chakrabarti [122], the research clarification phase is: “To identify the goals that the research is expected to realise, the focus of the research project; the main research problems, questions and hypotheses; the relevant disciplines and areas to be reviewed, and the area in which the contribution is expected.” The output of the research clarification phase is expected to be an understanding of current knowledge within the research area and the development of initial research questions.

Background and Problem Statement

A literature review provided insights into the nature of decision-making fundamentals, organisational decision-making difficulties, and the nature of decision-making in a product development context. As described in Chapter 3, the different approaches to decision-making enable a different understanding of the nature of decision-making and the practice of natural decision-making. In product development literature, e.g. Ulrich and Eppinger [65]; Ullman [5]; Andreasen and Hein [7]; and Clarkson and Eckert [50], there is a focus on making informed decisions through a structured approach, based on the prescriptive decision theory. There is little or no information describing the colourful difficulties of naturalistic collaborative decision-making. This leaves practitioners wondering what they are doing wrong when mistakes happen, even after implementing a structured product.
development model and methodology. A gap was identified between actual decision-making and the existing support methods prescribed by product development theory. The gap is how product development process models and methods are used in industry as a basis for effective collaborative decision-making. However, they do not support certain aspects of naturalistic collaborative decision-making. In order to support product development process improvements, it is important to develop knowledge about how the collaborative decision-making process can be viewed holistically (as a system) and include its relations to performance aspects. A holistic view of collaborative decision-making could be used for understanding the current situation in the organization, the preferred future state, and how to achieve it. Therefore, it is important to investigate what elements characterise a collaborative decision-making system.

A second research question was posed based on the need to identify what elements characterise a collaborative decision-making system.

RQ2 – What are the major elements and factors of collaborative decision-making in product development?

Empirical Findings in the Research Clarification Case Study

The analysis of the data gathered during the case study of Companies X and Y was based on two different approaches. The first approach was to simply ask the actors to describe how decisions were made at the company. The descriptions were then compared to the canonical decision-making model and conclusions drawn. The second approach was to ask the actors what they thought effected decision-making in the product development process and compare the data with two areas within literature, product development, and decision management. The literature on product development was categorised into “Perspectives on design”, “Design practise”, and “Design management”, according to Clarkson and Eckert [50]. The literature on decision management was based on Ullman [103] and used for creating a filter for the data. All the literature in both analysis approaches was used for identifying influencing factors, directly as well as indirectly.

The empirical results initially showed how the awareness of decision-making fundamentals and how to manage objectives, uncertainty of information, preferences, alternatives, criteria, structures, competence of actors, communication, and environment, was low. The low awareness of these aspects of decision-making resulted in difficulties in handling a wide range of product development activities (e.g. requirement engineering and risk management). This low awareness of decision-making fundamentals was called low decision-making maturity.
The result of the case study at Company X was viewed from two aspects: the actors’ view of the decision-making process at Company X, and factors affecting the decision-making process. Factors influencing the decision-making process during product development found in the two case studies were related to the following ten generic product development categories: (1) Handling of requirements, (2) Experience from earlier projects, (3) Organizational influence, (4) Project management, (5) Top management, (6) Knowledge and information, (7) Risk management, (8) Information systems, (9) Communication, and (10) Change management. The results can be seen in detail in Paper 1.

The result of the case study at Company Y is also described to some extent in Paper 1, but is also further described below. The case company's core competence is within heavy machinery development. No machinery components are produced by the company; rather, they are delivered by sub-deliverers and assembled, tested, and shipped to retailers as a whole product. The company is successful and have grown steadily for the last five years. The Company sell approximately 300 products per year on the global market, all of which are individually configured, with regard to mechanics and electronics, for individual customer needs.

The case study was initiated by a workshop with nine people from different departments in order to create an overall understanding of their product development process (including communication, areas of responsibilities, and decision-making). A total of 12 interviews followed and were held with people from the board of directors, market management, project management, engineering design, logistics, and production. The aim of the case study was to map the company’s management of their product development projects. Two projects were investigated, one successful and one not successful (according to the Company). During the interviews, the interviewees also commented on a second unsuccessful project to illustrate some of their points.

The result was divided into four sections, related to collaborative decision-making with focus on a project management level.

1. The Company’s shared overall view of their process.

The Company has a formal description of their product development process including critical decision points, but did not follow it in practice. They skip some gate decision points (market verification of design and field test review before production) because, after committing to the project at an early stage, their notion is that they freeze the specification in order to get the product to the market fast. This means that the specification should not be altered during the project, when in fact it is. That there are different versions that differ between finalized designs to start of production illustrates this.
"When the design work is initiated, it is a matter of getting the product to the market within our timeframe. After that (finalized design), it is about feeling content with what we got." (Statement of a designer)

The project managers tend to not communicate the state and plans of the overall project in an appropriate way. This was commented by a designer:

"...the overall state of the project is not discussed in general during the project."

By not communicating the overall state of the project, the experts have a hard time keeping a complete picture of the project in mind and reasoning about priorities for overall progress.

At a strategic level, it was stated that the priorities were: cost, quality, and time for the projects. However, when looking at the focus of decisions made, the priority tended to be quality (functionality) early on in the process, cost in the end, and time afterwards.

2. The decision situations of most value to project management.

The decision situations the project managers considered most important in order to communicate, plan, and reason about performance were the different planning and review meetings during the projects. The review meetings can best be described as the control function of project management, as described by Haffey [15]. Three organisational levels were involved during these meetings: a member of the project reference group, the project manager, and relevant experts. The planning meetings were few during the projects, and were about directing and organising activities and resources. The review meeting were where different relevant competencies gathered and discussed activities, plans, project and product changes, and product performance. The aim of the review meetings can be seen as the monitoring of the progress and deviations in order to control the satisfaction of goals. The weekly review meeting tended to be task focused, and was considered most significant in order to manage the communication, information, and progress of the project.

"The weekly review meetings are important in order to review and secure progress of the work." (Statement of a project manager)

3. The responsibility of project and design decisions?

The project manager is a part of the reference group and has largely been a part of setting the culture for decision-making in projects. Management does not focus on the efficiency of projects, so projects are managed without focusing on efficiency as well. Team members rely heavily on the manager to manage the whole of the project. A designer stated:

"One hopes for having an overall view when looking at consequences, but if someone does, it is the project manager."
When studying their decision-making and project success, with that statement in mind, it is clear that they tend to focus on the effectiveness and overlook the efficiency of projects. The project manager is responsible for the quality of the design and oversees the success of the project as a whole. Management of a successful project demands managing both the project’s progress and the final product.

4. The behaviour when making decisions in design projects.

The authors expected to see usage of support tools such as the ones described in Chapter 3, but there was no evidence of the use of support tools for the clarification of decision situations. Decision-making on an expert level is seen as an individual cognitive activity to a large extent within the company. On a project management level, decision-making is seen as product quality, cost and functionality control. When interviewing a designer, it was shown that design decisions were made individually and between review meetings.

"We discuss something on one meeting, solve it between meetings, and nail it down on the next meeting. I do not think we make any detailed decisions on the short time during the meetings…"

Between meetings, the expert prepares a suggestion for a solution to a problem. The suggestion is reviewed in a review meeting and either decided upon or the expert is asked to revise the suggestion. By so doing, management plans for upcoming activities in a rather sequential manner.

It seems that project management decisions were about overall product design (product structure, alternatives/optimization of design), timing of activities (what to do next), and progress (go/no go or revise), and were made in the planning and review meetings. These decisions were responses to the need of the project team at that specific time. Decision-making in the review meetings was a response to changes that occurred between review meetings. Finally, decisions made by the manager between meetings were more technical (participating in design decisions) and had the same characteristics as decisions made by designers.

Reflection and Conclusions from the Research Clarification Case Study

The two companies had different views of the decision-making process, due to different levels of decision-making maturity. Company X had difficulties handling the co-ordination of development tasks, which drew attention away from looking at the underlying decision-making process. Meanwhile, Company Y shifted focus closer to the decision-making process by looking at the related communication process, and to some extent viewed an
efficient development process as rapid decision-making. The different views of the decision-making process within product development projects could possibly be divided into levels of decision-making maturity. However, there was no attempt to make such a division in this study.

The actors’ ability to distinguish between the communication, information, co-operation, and decision-making processes is shown to be an important issue for successful product development, when it impacts on different aspects of decision-making performance. If a company tries to “cure” a problem by focusing on the symptom, the result will be failure. A clear conclusion that could be made was that both companies had little or no knowledge of the concept of “decision management” or the opportunities for improvement it could represent. This highlights the need for a “systems approach” to collaborative decision-making in product development.

Co-operation puts great demands on communication and information management, a situation both Company X and Y experienced. If the division of the different processes (i.e., information, communication and decision-making) is not clear to the involved parties, they tend to have difficulties identifying the underlying problem and focus on solving the symptom of the underlying problem instead.

Decision situations that occurred with the project manager and the group present involved planning (directing and organising) and reviewing (control). The planning meetings were few during the projects and concerned the timing of activities (what to do next) and progress (go/no go or revise decisions). The review decisions were where different relevant competences gathered and discussed progress, project and product deviations, and product performance. Design decisions were made mostly individually by experts and between review meetings about alternatives and optimisation of design solutions.

Neither company had a decision-making culture that supported the clarification of relevant aspects and the articulation of uncertainties when making decisions. Perhaps this is because the companies reuse a large amount of technical solutions and have been doing so for a long time, which results in their relying too heavily on experience and routines when making decisions. This in turn means that when they are forced to be more innovative in their development process, the project suffers from high costs and long development time due to a lack of consideration of the complex nature of product development projects, consequences, and project performance aspects when making decisions.

The notion within management at both companies was that the specification is frozen after concept development and no major changes occur. In reality, major changes do very well occur, and most likely impact the result. Early thoughts and estimations of the project and product as a whole are changed during development due to, for example, the
misinterpretation of market input or no functioning design solution options. The notion of a non-changing project environment results in difficulties in managing changes during development, due to a lack of consideration of essential aspects of the changed situation and its consequences, which impacts the planning and execution of activities.

The high level of unnecessary uncertainty when making decisions effected project cost, product cost, and project time. Project time and a “complete set” of requirements was the main focus of Company X, and resulted in the neglect of other essential decision aspects, e.g. decision analysis. Product performance and quality were the main focus of Company Y when making decisions in the projects, and this resulted in high quality products. The project managers in both companies did not consider the properties of project decision-making, i.e. project effectiveness and project efficiency.

In order to contribute to the answer to research question 1, the findings in the case study were related to the state of art by the supporting question: what aspects of collaborative decision-making can be considered to be important to manage? The findings led to two conclusions: (1) actors describe different aspects in their surrounding context and the main skills in order to manage and improve these aspects need to be further investigated, and (2) in order to manage and improve the collaborative decision-making process in product development, a shared view by actors making the efforts to improve the process is needed.

In order to answer research question 2, the findings in the study of Company X and Y were related to the literature, and a system of collaborative decision-making in a product development context was developed. The findings from the case study pointed to the importance of clarifying the performance aspects of the delivery (product and project tradeoffs), the objectives on different levels, communication (both formal and informal), the connection between processes on different levels, decision activities (both formal and informal), and the procedure of making decisions (strategies), which points to the current inability to manage the dynamics of collaborative decision-making. The literature points to nine elements that are of great importance for a collaborative decision-making system. These are: (1) the development process, (2) the structure of the process, (3) the performance of decisions, (4) the framing of decisions, (5) the organization, (6) communication in order to achieve objectives, goals, alternatives and to manage tradeoffs, (7) individual actors and their preferences, objectives, and judgment, (8) methods/tools, and (9) the product/delivery/output. In order to clarify the connection between decision-making, performance of decision-making, and the product development organisation, a “Rich Picture,” including the identified elements of collaborative decision-making, together with an organisational performance model (Figure 17), was developed. When combining the two, they show how it is possible to view product development as a collaborative decision-making system (see Figure 15 on the next page).
Figure 15. The collaborative decision-making system of product development.
The included organisational performance model (called PDOPM) is a model which can be used for discussing the connection between decision-making and product development activities, as well as evaluating decision-making performance and uncertainty in a product development organisation (see Figure 17). The proposed PDOPM makes it possible to reason about, and assess, efficiency, effectiveness and uncertainty of decision-making within the three generic levels of activity: product strategy, project management, and product activities. The uncertainty aspect may be viewed as a comparison between the current knowledge of the input and the stated goal (see Figure 16).

Figure 16. Effectiveness, efficiency, and uncertainty.
Figure 17. The Product Development Organisation Performance Model (PDOPM).
Why the three levels of product strategy, project management, and product activities were proposed was due to their differences in required organisational capabilities in order to be successful. Product development is dependent on all of these three levels to function well in order to be successful. Each generic level of decision activities in the PDOPM uses resources to convert input to output, under the constraints of goals and objectives. The goal of the product strategy activity level is related to business strategies, and the output from the activity serves as goals for project management activities. Project management translated goals into output, which serve as goals for the product activities where the product is realised.

If the output of a task or decision on a specific level in the organisation is compared to the goal, effectiveness is determined. If the relationship between output and input are compared with used resources, efficiency is determined. However, both effectiveness and efficiency are influenced by uncertainty in decision-making. The uncertainty could be present as uncertainty of the basis on which a decision is taken, goal or input. If input and goal are compared, it is possible to understand the impact of uncertainty (\( \mu \)) in decisions, actions and consequences. Further, uncertainty can affect the purpose of the decision, i.e. the created value. The difficulty of viewing the whole of a product development organisation as a decision-making system is decreased by the model, which connects performance aspects, from a strategic level to an operative level. Decisions can be linked within all of these contexts. The rich picture (Figure 15) connects the performance perspective of the organisational contexts with the decision context. The PDOPM model is presented in more detail in Paper 2.

The Descriptive Case Study

According to Blessing and Chakrabarti [122], the Descriptive Study phase aims at increasing the understanding of the phenomenon and its success factors. This is achieved by investigating the phenomenon through literature reviews about empirical studies, empirical research, and through reasoning. The output of the descriptive phase is a basis for the effective development of support for the success of the phenomenon.

A description of Company Z can be found in Appended Paper 3.

Background and Problem Statement

With the results and conclusions from the Research Clarification phase, a new literature review was made focusing on decision-making aspects in product development. There are
some authors that address decision-making in product development specifically, providing insight into specific aspects of decision-making. Gidel [97] provides a framework for the planning activity of decision-making; Hansen and Andreasen [96] propose a model for a mindset of engineering design decision-making; Jankovic [12] provides a framework for mapping and structuring the decision-making process; and López-Mesa and Chakrabarti [48] provide insight into how designers actually synthesize alternatives. Still, the question remains of what, and how, the actors perceive and account for the main factors influencing the decision situation when making decisions. That is what the actors base their decisions on and what needs to be understood. The comparison of what actors perceive to influence collaborative decision-making and what theory describes to influence collaborative decision-making is interesting in order to understand and evaluate actors’ decision-making behaviour, strategies and influencing factors.

With that in mind, a third research questions was posed;

| RQ3 – What factors do actors perceive to effect a collaborative decision in product development, and how do the factors relate to the decision-making literature? |

Empirical Findings in the Descriptive Case Study

A single decision was investigated by first mapping activities considered by actors to be important for the decision-making process (see Figure 18).

Figure 18. The identified important activities of the decision-making process.
The empirical findings in the descriptive case study showed that actors perceive influencing factors as a diverse range of factors on different levels (e.g., decision making responsibilities) and processes (e.g., requirement management). There were 37 different factors related to their decision-making considered by the actors to have influenced the specific decision. The factors were related to three generic aspects of collaborative decision-making: Environment and structure, enablers, and procedures (see Table 4).

**Table 4. Perceived factor that related to their decision-making process.**

<table>
<thead>
<tr>
<th>Environment and structure</th>
<th>Enablers of decisions</th>
<th>Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>An overview of decisions</td>
<td>Decision criteria</td>
<td>Scope management</td>
</tr>
<tr>
<td>Competitors</td>
<td>Trade-offs</td>
<td>Planning and control</td>
</tr>
<tr>
<td>Functional integration</td>
<td>Commitment</td>
<td>Manning</td>
</tr>
<tr>
<td>Processes</td>
<td>Constraints</td>
<td>Strategies</td>
</tr>
<tr>
<td>Structures</td>
<td>Alternatives</td>
<td>Decision procedure</td>
</tr>
<tr>
<td>Authority</td>
<td>Intuition</td>
<td>Coordination</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>Rationality</td>
<td>Change management</td>
</tr>
<tr>
<td>Decision culture</td>
<td>Decision premises</td>
<td>Objective creep</td>
</tr>
<tr>
<td>Politics</td>
<td>Goals</td>
<td>Information flows</td>
</tr>
<tr>
<td>Roles</td>
<td>Market need</td>
<td>Resource management</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>Information</td>
<td>Decision methods</td>
</tr>
</tbody>
</table>

Some examples of statements are given here. Goals for the decision activity were considered to have been a weak point in the decision making process. An example of a statement is:

"They (main project group) work a long time and would like us to work at full speed at the same time when they haven’t provided the goals yet. We should let the early phases take the time they need and work only after having decided (on the goals) instead of fooling around with the requirements."

Alternatives were described as an activity, but without stating how they were developed. The interviewees said that they delivered four alternatives, but just stated that it was a
matter of collecting available information, determining costs, categorising, and summarising. No explanations of how alternatives were first developed were described.

“We develop alternatives, check the tradeoffs, and pass it on for final choice.”

Decision-making procedures were often described on a generic level. They were described as a part of a series of activities. No description of a full decision procedure was given. An example of a statement is:

“When one is to investigate consequences within the whole (of the project) and in detail, the first thing is to bring it up (the alternatives) in the project team so all get to go home and look at the impact it has on their specific area, and bring the conclusions back. Otherwise it is easy to miss something that will impact on a certain aspect.”

Criteria for decisions were described as cost, time, and quality, but also risk tolerance. Two examples of statements are:

“We checked the cost and necessary resources and took it to the steering committee which said that it was too much money right now and also that it was too much risk with the "new content".”

And

“The time plan is the most obvious guiding means also when it comes to goals. That is, the goals and requirements we put up are relevant as long as we can reach them within the time frame set in the project.”

Consequence analysis was described as a way to understand consequences, as well as a means to influence the steering committee’s direction with old, and new, decisions.

“My part was to calculate what the cost would be in the end for the customer regarding the alternatives. … What we also wanted to show with the calculations was that we could deliver a higher value for the customer without implementing the decided direction that was being investigated.”

Uncertainty (in knowledge) was considered to be a great problem in the decision and in general. An example of a statement is:

"We make decisions with great uncertainties but act as though we are sure. I think that the decisions we are uncertain about, and where we risk making decisions on uncertain grounds, we get to regret in the form of quality deficiencies later on in the process, thereby losing market shares and all that follows with competitive advantage and profits."

Tradeoffs were not mentioned explicitly, but were mentioned as an argumentation about market needs, investment costs, uncertainty in assessed production volumes, and the
uncertainty of the value chain. That argumentation was central to all actors involved in the decision, without the interviewees mentioning the word tradeoffs once.

*Information* (uncertainty) was also described as a barrier to efficient communication and understanding between actors. It was stated that information was hard to understand in regard to the actor’s own point of interest. Also, the different levels in the organisation treated information certainty in different ways. One example is:

"Depending on where we are in a project, in relation to the development model, information means different things. That fact can definitely be an explanation for why the management level in the organisation writes (early developed) things in stone too early."

**Reflection and Conclusions from the Descriptive Case Study**

Out of the 37 factors, there were eight factors that directly related to decision-making literature (which was chosen to be presented in the previous section) which was chosen through a comparison with the Collaborative Decision-Making System (Figure 15), and a list of main aspects of collaborative decision-making theory. The eight main factors that directly related to decision-making literature were:

- Goals
- Alternatives
- Decision-making procedures
- Criteria
- Consequence analysis
- Uncertainty
- Tradeoffs
- Information (uncertainty)

These main factors were compared to decision-making and product development literature, and relations were sought. The analysis was conducted by categorizing findings into elements and factors of the collaborative decision-making process.

The way the interviewees described the decision made showed that they had different preferences related to their responsibility and personal views of what decision-making should be like. Also, the interviewees described the decision in two ways: either as a small chronological section of the whole decision-making process, or as a linear process from start to choice of alternative. Some also perceived their small (but crucial) part in the decision as a
A task with a clear output that contributed to a specific aspect (understanding of specific criteria) in the decision-making process.

A common view the interviewees possessed was that making the decision was a collaborative activity that relied on the input from actors throughout the organisation (different levels, departments, and locations).

A structured and clear approach to how to work with goals on different levels of the organisation, and between departments, is a critical performance driver. This is not news. Nonetheless, it seems a hard thing to identify as important input in decisions in this case. There is little evidence that suggests such a structured approach in the studied decision-making process. A project manager stated: “We often start working and keep working, even though the overall goals are not formulated on our level yet.”

Decision-making procedures are seen as communication of information in order to investigate consequences of given alternatives. By working on alternatives as a part of the decision-making procedure, the operational levels of the organisation could contribute by creating alternatives about the issues that arise.

The management of requirement seems to be a central issue, and it is a source of difficulties which they strongly relate to collaborative decision-making. A manager stated: “An issue that keeps coming up is the structured management of requirements. It is non-existent and especially the change management of requirements, first getting them into place and then handling the changes with their consequences.”

The study showed that the most important deliverable to the customer was considered to be a specific quality parameter (a product performance aspect). However, the tradeoffs shifted toward the end, and it was later identified as time and cost, which implies that quality is out of focus in tradeoffs in decisions. One of the project managers said that: “Cost comes first, then time, and quality is implied but not in focus”. It was hard to get a clear view of the priorities in tradeoffs, and they tended to be used in an ambiguous manner.

The results also point to the finding of four main elements that actors perceive to constitute the context of collaborative decision-making. These elements are the process itself (decision-making process, output, input from different levels, and procedures), the methods to use (in decision and consequence analysis), and the management of requirements, in order to develop and deliver a product.

The actors would benefit from increased awareness of the relationship between different parts of the decision and overall objectives and performance aspects in order to manage the tradeoffs. This could be done with a further development of the Collaborative Decision-Making System in the specific context of the organization. Further, an increased awareness
of the decision-making strategy employed would increase the possibility of a good enough decision. A model of the relationship between all of these elements can be developed and is seen in Figure 19.

Apart from the identified elements in the context, several other important related aspects to consider in collaborative decision-making were found.

*Alternatives* are proven important in order to make high quality decisions, but are not a prioritised activity in the decision-making process in this case. Alternatives are often given by a steering committee, and not developed in a methodological manner. It is an activity that is based on a group’s knowledge about the system as a whole. The decision studied in this case was one where the accumulated knowledge of the group was just not enough to consider the consequences on the system as a whole. The decision was redone, with a loss of time and money due to a lack of understanding of the behaviour of the system.

*Criteria* used for *analysing predicted decision output* is mainly focused on cost and time. Other criteria were used (such as final market price, and amount of new content in solutions), but they were used in an ambiguous ad-hoc manner when discussing criteria. The criteria used are a result of what management is measuring. Hauser and Katz [123] stress that the every metric used will effect actions and decisions. In the study, what is being measured is clearly what is being considered in decisions. The decision culture in the company mainly focuses the usage of criteria towards cost and time, which impacts on the consideration of other performance aspects of decision-making.

*Consequence analysis* of decisions made in the steering committee about the product characteristics and properties were documented in order to monitor the progress of the project on a high level in the project. This was made to sustain a holistic view of the
product development project. The documents are a part of the Stage Gate Process Model and serve as a strategic objectives-document in the project. Decision analysis on a tactical and operational level had not been used in a structured manner at the time of the study. However, after concluding the study and returning to the Company for a validation of the results and conclusion, the usage of decision analysis had been introduced. It was still not a standard in the company when analysing decisions, but it was a great step in the right direction. The new decision analysis consisted of a structured way of presenting the background of the decision issue, consequences of suggested alternatives, and recommendations to the steering committee. It enables the development and use of a support method that increases the amount of informed decisions. It could be developed to include, for example, decision approach, decision-making process investment, criteria prioritising, tradeoffs, and acceptability.

Uncertainty (of knowledge) was not described as a part of the decision analysis and means that the level of uncertainty is not explicitly expressed by actors in the group. The awareness and management of the knowledge level in the group is vital for a group to reach an informed decision. Ullman [103] presents a simple and effective method for this purpose called a “Belief Map,” and clarifies criteria satisfaction and knowledge uncertainty in a decision situation that could be used in the decision analysis work by the company.

Tradeoffs are guided by the overall goal of the product development organisation. “Good, fast, cheap... pick any two” [124] is the usual response to fast decisions in a product development context. The strategic tradeoffs can be illustrated by a triangle that a point needs to be placed within (see Figure 20).

**Figure 20. The triangle of cost, time, and quality.**

Information uncertainty was considered to be an issue because the premise, on which that the information was valid, was not presented in a clear way. Information that was understood clearly and considered certain by one actor in a department was considered uncertain by another actor in another part of the company. There was not sufficient communication and information in order to create a shared understanding of the decision issue. The distance
between actors in the company demands clear communication, information, and understanding of different actors' responsibilities.

In conclusion, the identified elements and influencing factors of collaborative decision-making can be summarized by relating them to overall aspects of the task of collectively reaching an agreement on objectives and using those objectives in order to reach a satisfying decision on performance tradeoffs. In order to perform this task, there are three overall factors of great importance identified in the literature and the case study that can be used for the summarization: (1) the ability to frame a decision situation, (2) the procedure used for reaching the decision, and (3) the methods used during the procedure in order to reach a decision (see Figure 21).

![Figure 21. Competencies for collaborative decision-making.](image)

Framing is vital for collaborative decision-making, and includes the capability of determining needed expertise (domain knowledge) in decision situations. The organisation also needs to provide means for the actors to know what they can and cannot do in a decision situation. The actors need to be able to clearly identify the constraints and possibilities of decision situations. Also, the actors need to be able to identify the group’s
“wants” in relation to overall strategies in the organisation. There need to be clear goals on different levels and in different domain groups in the organisation in order for actors to understand the role of the decision in the organisational performance perspective.

Procedures, the way actors behave when making decisions, are impacted by their shared preferences and roles in the organisation. The behaviour becomes the strategy and tactics of the group of actors, consciously or not. The preferences are what the actors in the group value and the relation to overall values of the organisation. It is a large part of the culture. The role of the group in the organisation needs to be clear in order to understand the contribution to the collaborative decision. Actors may switch roles during the process, and they must be able to understand the current role in order to deliver an appropriate value.

Methods of support are vital in order to manage the collaborative decision-making process in a product development context. Rules, often embedded in the organisational culture, are an effective and efficient way of managing collaborative decision-making. But they are also hard to influence. Techniques like QFD, FTA, FMEA, and Decision Analysis serve to enhance our ability to understand relationships and dynamics situations that otherwise would be considered too complex. Infrastructure in the form of formal decision structures (e.g., product development process models, IT systems, instructions, manuals, and templates) are the way organisations structure the responsibilities, authority, relevant information, and decision issues of actors. This aspect has been extensively researched in product development literature.

The competence model is intended to summarise the understanding of what is needed to manage in order to ensure effective, and efficient, collaborative decision-making in a product development context.

What these aspects of collaborative decision-making showed was that there is a great potential for identifying process improvements by observing decision-making practices in relation to fundamental decision-making theory. The fundamental decision-making aspects act as a basis for understanding the root cause of different difficulties and connect the aspects to a process, from a fundamental to a strategic level in the organisation.
CHAPTER 5

CONCLUSIONS, CONTRIBUTION, AND FUTURE WORK

This chapter introduces the conclusions of the case studies and the research as a whole by answering and discussing the research questions. The contributions and fulfilment of the objectives of the research are discussed, and future work is presented.

Conclusions

The objective of this research was to enhance the understanding of a decision-making focus as an enabler for product development process improvements. Three companies were investigated within two case studies, and this contributed to the overall understanding of elements, factors, and difficulties of collaborative decision-making, as well as its relation to performance and decision theory.

The research clarification stage investigated the actors’ view of decision-making and how they reasoned about decision-making as a part of the product development process. The study showed that the two investigated companies had low decision-making maturity, which meant that the awareness of decision-making as an important aspect of the product development process was low. This low awareness affected, for example, the decision-making culture, decision-making structures, decision-making methods, decision-making behaviour, and the decision-making process. It also showed that actors have difficulty relating the product development process to performance aspects. In order to be able to clarify the connection between a product development process, decision-making, and performance aspect in an organisation, a “rich picture” was developed together with the PDOPM. The two models are parts of a collaborative decision-making system and enable the distinction between different performance aspects related to collaborative decision-making.
The descriptive case study investigated what decision-making actors’ perceive to affect the decision-making process. The findings pointed to a fragmented awareness of influencing aspects on decision-making, and no shared view of the decision-making process was to be found. The different factors that actors perceived to affect the decision-making process ranged from fundamental aspects of decision-making to product development process activities and methods. The factors could be related to the context of actors in collaborative decision-making and three different aspects of the system: framing, procedures, and methods. The three aspects contain nine competencies that represent the identified factors in the case study and literature needed for the management of collaborative decision-making.

Fulfilment of Objectives

The objective of this research was to enhance the knowledge of collaborative product development process improvements that focus on generic decision-making abilities in relation to overall process performance. As described in the research clarification and descriptive phases, the enablers, difficulties, and factors that effect collaborative decision-making have been investigated. By answering the research questions of this research, the objectives of this research can be considered fulfilled.

| RQ1 – What is decision management in collaborative product development? |
| The first research question, a part of the research clarification phase, was answered by compiling a state-of-the-art of collaborative decision-making in collaborative product development and its relation to performance. The “Frame of Reference” summarised the literature used as a basis for the research. Also, some early findings in the case study in Company X contributed to the answering of research question 1, and research question 2 was stated. |

| RQ2 – What are the major elements and factors of collaborative decision-making in product development? |
| In the case study of Company X and Y, there were both elements and factors identified and related to performance aspects of the product development process and the organisation. Taken in relation to the literature, the case study results provided a basis for a “Rich Picture” that illustrates a system of collaborative decision-making and its relation to performance aspects of the product development process and the organisation. |
Thirty-seven factors effecting collaborative decision-making were expressed by eight actors and identified. Further, eight factors directly related to decision-making theory. The factors points to the characteristics of the product development process, i.e. dynamics, detailed complexity, and a high level of uncertainty. The need for a clear view of the role of collaborative decision-making in the product development process in order to differentiate between the cause and effect of difficulties in the organisation is highlighted. If there is no shared view of the system of collaborative decision-making, the actors’ decision-making behaviour becomes just as fragmented as their view of influencing factors.

The identified factors were related to the literature, and three aspects of the collaborative decision-making system were found. These three aspects include nine competencies necessary for the ability to manage the system.

**Contribution**

A significant part of decision-making theory is difficult to apply in real-time, complex decision-making. There is a well-structured body of knowledge about decision-making aspects, e.g. politics, power, and communication in the organisational theory of decision-making. This research focuses on the real industrial need of being able to continuously improve the performance of the product development process in order to stay competitive on the global market. However, there has been little written about how companies can actively and continuously work to improve their ability to make high quality collaborative decisions on a holistic generic level. There has been little written about how to handle such activities in the engineering design theory of decision-making. However, decision-making theory in relation to the results from the empirical studies provided new aspects regarding the use of decision-making fundamentals in product development process improvements. A holistic approach to performance, combined with decision-making theory and product development literature, enables new knowledge to be generated that connects decision-making theory with applications in an industrial setting.

The first contribution was a model of the Collaborative Decision-Making System. It clarifies the relations between the process, decision-making, and performance aspects.
The second contribution was the identification of elements of the actors’ context in collaborative decision-making in product development. It identifies six elements related to decision-making procedures, processes, and methods.

The third contribution was the identification of competencies necessary in order to manage the whole of the collaborative decision-making system. The nine competencies relate to three aspects of the system: the ability to frame decision situations, the ability to manage decision-making procedures, and the ability to support the system through methods.

The fourth and final contribution, industrial in nature, is in the form of the holistic models of the collaborative decision system. They could enhance the awareness of important aspects of collaborative decision-making and its relation to performance and the organisation. The need of the research has its roots in industrial settings, and the results reflect that fact. All results aim at providing industry with the increased ability to enhance and handle collaborative decision-making.

Quality of the Research and Validity of the Results

What distinguishes a researcher from a non-scientist is not what is being studied, but rather how it is being studied [22]. Therefore it is the quality of the process that is important to evaluate. That implies a systematic approach and the use of accepted methods in order to trace the line of thought throughout the research process. The research has been performed in the way described in Figure 1 and in accordance with the Design Research Methodology [23]. The process phases and activities have been documented using, for example, interview protocols, presentations, documentation, and scientific publications. The quality aspects of this research regarding reliability, internal validity, and external validity were further discussed in Chapter 2.

Finally, some of the possible questions and critique of this research are presented below:

- Few case studies of the phenomenon limit the ability to generalise the results.
- Interviews with actors offer a limited ability to investigate the behaviour of actors.
- The data is analysed by the researcher with his background and current understanding of the phenomenon and may impact the analysis of the data and in turn the results of the research.
Future Work

During the research process, there were many questions found that would be interesting to investigate further. Some of these questions are presented below as areas of future work.

Best practice of collaborative decision-making

It would be useful to find an organisation that regards their collaborative decision-making practices as well functioning. The case could result in the finding of how they view their process, decision quality, and decision performance. The case could be viewed as best practice and be compared with the research findings in this thesis. The strategies and tactics used in the different cases could be compared and differences investigated. The results could be used in order to investigate enablers of collaborative decision-making.

Formal and informal activities of collaborative decision-making

Finally, in order to investigate strategies and tactics used by actors, it is interesting to make observations of real-time complex collaborative decision-making in a product development context. The interviews held up until now have shown that the actors express most of all formal aspects of decision-making and tend to be unaware of informal aspects when discussing activities of decision-making. Therefore, the intention is to observe collaborative decision-making during a long period of time at a Swedish company in order to investigate both formal and informal aspects that influence collaborative decision-making, as well as how actors make collaborative decisions and how their ability could be enhanced. The results could be used to develop a framework for decision-focused product development process improvements.
REFERENCES


[107] Dylla, N., Thinking methods and procedures in mechanical design. 1991, Technical University of Munich, Germany.


Efficient Decision-Making in Product Development

EFFICIENT DECISION-MAKING IN PRODUCT DEVELOPMENT

Joakim Eriksson¹, Björn Fagerström² and Sofi Elfving³
¹,³PhD student, Innovation, Design and Product Development, Mälardalen University, Eskilstuna, Sweden
²Professor, Innovation, Design and Product Development, Mälardalen University, Eskilstuna, Sweden, and Ohde & Co, Göteborg, Sweden.

ABSTRACT
Product development projects need to be managed in a timely and efficient manner in the present competitive business environment. The authors of this work argue that the commonly used product development models do not fully meet this demand, and the decision-making process needs to be made explicit.

This work mainly focuses on the product development process. Two companies were studied using case study research. The aim of the case study was to identify key factors affecting the decision-making process in product development. The type of collaboration used in these two companies was also investigated in order to identify the influence it had on the decision-making process of each.

The two companies had different views of the decision-making process which were related to their level of development process knowledge. Common factors affecting the decision-making process in product development were divided into ten categories: (1) Handling of requirements, (2) Experience of projects, (3) Organizational aspects, (4) Project management, (5) Top management, (6) Knowledge, (7) Risk management, (8) Information systems, (9) Communication, and (10) Change management.

Keywords: decision-making, product development efficiency, co-operation.

1 INTRODUCTION
In a competitive environment, where products from different vendors often have the same levels of performance, quality and functionality, the process of developing innovative products at a lower cost and within shorter time intervals than competitors becomes increasingly important. In addition, vendors need to be flexible in order to respond to changes in markets and new technologies.

Product development is a complex process, and many aspects influence its outcome. Examples of such aspects include project planning, requirement management, co-operation, knowledge and competence, project management, IT-support, and decision-making. It is argued in this work that an explicit decision-making process is one crucial aspect of efficient project execution. A decision-making process not functioning well may result in unplanned rework, delays and increased uncertainty. Product planning decisions are more closely related to effectiveness while decisions in product development projects are more closely related to efficiency. This study is focused on operative decisions related to the product development process, a process whose aim is to make sure that the product fulfils the defined requirements and targets, within time and budget.

The purpose of this work is to further explore various factors influencing the decision-making process, and how the concept of co-operation may interact with the decision-making process. This knowledge in turn will facilitate a more efficient and stable execution of product development projects. Two companies have been studied using case study research. Three research questions were addressed during the study: (1) What are the companies’ views of their decision-making process within product development projects?; (2) What do the companies consider affects the decision-making process during product development projects?; and (3) How does their level of co-operation affect the
decision-making process? A filter was used for interpreting and analyzing the data collected during the case study. The filter was based on Ullman’s theory of decision management [1].

There are several interlinked activities that need to be coordinated and managed in order for a product development to succeed, and the decision-making process may be one of the factors that influences the output most of all. It is also vital for the entire product development process that all essential decisions and their consequences are analyzed. The appropriate information needs to be available, combined with personnel that have sufficient knowledge and skills to make a well-grounded decision. The decision-making process in product development rests upon three essential aspects: (1) the ability of personnel to manage the decision-making itself; (2) an appropriate organization for decision-making; and (3) the ability to utilize tools for decision-making and the decision-making process. These three aspects served as the adapted filter.

2 THEORETICAL FRAMEWORK

The theoretical framework for this work was chosen from earlier research conducted by Ullman [1], Elfving and Fagerström [2], and the case study which they conducted. Central for this work are the concepts of product development efficiency; information and knowledge management; co-ordination and communication; and decision-making in product development.

In this work, product development is considered a process for the transformation of different stakeholders’ needs into output information, which corresponds to a product design suitable for manufacturing. A large amount of information has to be coordinated in the product development process. In addition, the process itself requires and produces a lot of information that has to be managed as a part of the process. An efficient decision-making process and management support is also needed in order to support the project execution. The knowledge and experience related to the product and process will also influence the ability to take balanced decisions.

There is a wide range of factors influencing the outcome of product development [3]. In order to manage product development projects in a collaborative context, 19 factors and five categories were identified by Elfving and Fagerström [2]. Among others, integration, co-ordination, communication, trust, knowledge management and the decision-making process are factors that influence the outcome of collaborative product development projects. Each factor differs in importance, depending on the type of project and the level of collaboration required [2], [4].

2.1 Product development efficiency

Communication and the exchange of information influence decision-making and the execution of the product development process. Efficient information processing and decision-making are important for the task performance of a group.

Two different models related to efficiency will be discussed. The first model comes from the management consultant perspective. The authors Karlöf and Östblom [5] have drawn the following distinction between productivity and efficiency. Productivity relates to the cost per unit produced, while efficiency reflects the customer value in relation to productivity. The customer value may include quality, function, price and service. High overall efficiency is dependent on both productivity and customer value.

The second model originates from engineering design. The authors Duffy and O’Donnell [6] propose a model based on the IDEF0 formalism. The product development function is an activity or number of activities. The control mechanism is represented here as the goal/constraints and resources respectively. The input is represented as knowledge, information and/or data. It is transformed by an activity/activities, resulting in an increase in one or more of these elements, when delivering the output. The efficiency is defined as the difference between input and output, related to the resources (cost). The effectiveness is defined as the relationship between output and the goal/constraints. The performance is the combined measure of effectiveness and efficiency.

The models have some similarities at a general level. Both models have an outer dimension, often referred to as effectiveness. In addition, both models have an inner dimension, related to the process performance, often referred to as efficiency. The overall performance is related to effectiveness and efficiency.
Gate-models are commonly used in industry in order to improve the quality of the process execution. The gate-model can also support the project leader, serving as a road-map and to ensure that no important part of the process is missed. The model will also support internal communication. However, it is argued that the gate-models can also delay decisions, due to waiting and buffering effects. Furthermore, they do not give guidance on how to take decisions. Instead, the decision-making process should be made explicit and support those involved in product development, which will result in a more flexible and efficient product development process.

2.2 Information and knowledge management
Collaboration in product development relies on efficient management of the information exchange. The right information should be available to all involved at the right time [7]. An efficient organization also has to understand information-processing logic and its integration into the total environment in order to make appropriate decisions.

The success of engineering companies is highly dependent on how well product design information is managed and communicated [8, 9]. Engineering designers use information from a variety of sources to undertake a wide range of design tasks. It has been shown that engineers spend as much as 30-35% of their time searching for and accessing engineering design information [10, 11]. When engineers gather information, suppliers are often the mostly commonly used information source. Without access to accurate, up-to-date information, engineers may make mistakes or misjudgments on aspects of the product design. Groups can sometimes make bad decisions by not considering all relevant information and not appraising the full range of options available [12, 13]. It is also common that engineers prefer to use the information they already possess instead of searching for new input [14].

It is a mistake to equate knowledge and information, and to assume that difficulties can be overcome using information technologies [15]. New knowledge cannot be shared in the same, friction-free way that information is. Efficient handling of IT tools assumes that the organization has a common interpretation of different contexts, which is uncommon. Where a common understanding is lacking, computer tools only allow one to exchange information, not share knowledge. Organizing for exchanges of knowledge has a great deal to do with culture and behavior. As such, it is usually meaningless to begin by investing in software [16, 17].

2.3 Co-ordination and communication
Collaborative product development can be considered a complex activity. The co-ordination of many aspects of a question, together with the interaction of different involved parties and problems, often need to be solved in an integrated manner (i.e. together with a shared basis of information). Communication and the exchange of information will influence the execution of the process. There are many objectives for communication. For example, solving problems, decision-making, integration, exchange of information, access to knowledge, or motivating people are such objectives.

Effective product development requires the co-ordination and communication of market efforts, design and production [18, 19]. Distributed product development stresses the need for efficient communication platforms that support co-operation between multiple actors for the exchange of product development information [20]. Nonetheless, one shortcoming is that product data is handled in a heterogeneous environment, which includes incomplete, redundant and inconsistent product development information [21]. This is a demanding problem within the decision-making process.

Frequent communication also enhances the organizational commitment, leading to individuals that feel they are part of the project. Finally, communication may also reduce the negative effect of rework [22] by eliminating unnecessary activities, while it is also argued that poor communication might result in project failure [23].

2.4 Decision-making in product development
The product development process model which is used defines the actual process, allowing everyone in the development team to understand decisions rationally, and preventing the organization moving ahead with unsupported decisions [24]. However, it is argued that the decision-making process needs to be made explicit as well, to fully support competitive product development.
Explicit decision-making may be applied in different creative activities, from engineering design to business strategies, though they differ in their application. This is possible because of the shared features of decisions which are; the need to distinguish the quality of the decision from the desirability of the consequence; the need to include uncertainty and to value experiments, tests, and other forms of information gathering; and the need to establish preferences for outcomes. NRC expresses this in the following way: “Recognizing the similarities of all decision processes allows us to use important general insights in applying them; this is particularly true for engineering design” [25].

Decisions within engineering design can be divided into different categories depending on the nature of the decision. One perspective is activities in the product development process, and Krishnan and Ulrich’s “decision framework” includes approximately 30 major areas of decisions at a project level, divided into categories [26]. They found that although different organizations make different decisions during product development, they all make decisions about groups of common issues.

This is true regardless of whether the process follows a traditional product development process [27] or a stage-gate process [28]. All these processes are characterized by the production and distribution of information, interspersed by decisions, and it is the quality of the decisions that determines the time, cost and quality of the result. To be able to manage the decision-making process it is necessary to apply decision management. Decision management is the merger between On-line analytical processing (OLAP), collaboration tools and decision theory. It supports teams, enabling them to make level-headed decisions based on incomplete, uncertain and evolving information. Decision management is used to improve both effectiveness and efficiency of the product development process.

O’Donnell and Duffy presented a performance measurement and management model which includes both effectiveness and efficiency but still, in comparison to manufacturing for example, it displays a lack of concrete measurement methods for the product development process [29]. These measurement methods should be further developed in order to support decision-making and learning (knowledge) as well as enabling decision management to better support the development process.

It is also vital to learn from the decisions that are made. Hatamura [30] writes that besides the need for knowing the decision process, it is important to be able to describe and transfer the decision-making process. This is also an important role of decision management.

Ullman [1] (2006) defines decision management as; “Decision management is determining what to do next with the available information, making the best possible choice with known risk as a transparent part of the process, and documenting the result for distribution and reuse”. This will serve as the definition in this work. Ullman highlights the important components of managing the decision-making process. These include structured evaluation of existing information, including risk management in the decision-making, and documenting the decision rationale and results. In short, it provides a good overview of how to frame a problem, develop criteria and alternatives, and how to reach a decision. However, it does not provide methods for how to plan and measure the efficiency of decisions in the process, or how to manage the decision-making process in regard to how to identify critical decisions related to success factors in product development.

3 CASE STUDY
A case study was used as the main strategy for collecting empirical data. The aim of the case study was to identify the company perspectives of the decision-making process. Different factors that affect the decision-making process in product development projects have been identified and also discussed with the case study companies. Different principles of collaboration were also investigated in order to see if they affected the decision-making process.

The case study involved two companies, Company A and Company B. The first company was studied during two phases, in 2002 and in 2006, with the aim of studying possible changes at management level and management’s view of the decision-making and the product development processes. The second company was studied in 2006 and 2007, with the aim of collecting data in ongoing product development projects and in the related decision-making processes. The aim was to come as close as possible to the studied phenomena.
3.1 Method
Case study research was the preferred strategy to use, since 'how' and 'why' questions were posed. Generally, the case study approach was used as a strategy because it is a qualitative research method suitable for investigating current phenomena in their natural contexts [31] in order to better understand the dynamics of systems [32]. It was also employed because it is a relatively easy way to investigate inter-organizational relationships [33]. A case study copes with typical technical situations, and has the advantage of relying upon multiple sources of evidence. The data collection was, in both cases, made through open interviews, semi-structured interviews, and an overview of project documentation. A literature review was conducted within the fields of efficient product development and decision-making in order to facilitate the identification of interview areas and critical factors in the case studies.

3.1.1 Case Company A
In 2002, the company was located in a mid-sized city in Sweden. At that point, the company had 25 employees but was expected to grow. The core competence was within electronic technology development (e.g., electronic circuit boards for guidance systems). The company had mainly customer oriented product development, meaning that all work was based on customer orders.

During the 2002 study, interviews were made in two rounds. First, interviews were held to further identify interview areas and to complement the data gathered from the project leaders. Second, five project leaders were interviewed, considering eight different product development projects. In total, twelve semi-structured interviews [34] were conducted during the study.

In 2006 the company had grown from 25 to 38 employees. The company was still situated in the same accommodation, but now suffered from lack of space. The company was still expected to grow, and during the year several recruitments were made.

During the 2006 study, in total five interviews were held with, e.g. CEO, Market Manager and Product Development Manager. Just like in the 2002 study, the interviews were semi-structured. The analysis of all the interviews (both in 2002 and 2006) was performed according to Kvale’s so-called sentence concentration [35]. The most essential results from the interviews were interpreted and summarized according to this method of analysis. The results from the two studies were compared, looking for risks, opportunities, similarities, and differences between the two. Also, a filter was used for interpreting and analyzing the data, further presented in section 1.

3.1.2 Case Company B
In 2007, the company was located in a small-sized city in Sweden. It had, at the time of the case study, 50 employees and was not expected to grow in the near future. The core competence was within heavy machinery development and manufacturing. Three different types of projects were chosen in co-operation with Company B and included: a full product development project; the revision of a product part; and the development of a new product part. The reason why these types of projects were chosen was due to the different natures of the information processed during their product development.

A three-day study was held in 2006 to identify the decision-making process within the company’s product development area. The decision-making and information processes were illustrated with the help of interviews and discussions with, in total, nine people.

In 2007, a total of four interviews were conducted with people from the Board of Directors, the Managing Director, the Market Manager and the Product Development Manager. The documentary information was important during the case study. The collection of data included management documentation such as the product development process model, project plans, and the project documentation system, among others. A background to the case was established, and an understanding of the information system and decision-making process reached, with the help of the documentary information.

During the first analysis of the decision-making process and the information system, the data was categorized into the following: 1. necessary information 2. area of responsibility 3. decisions made and 4. the decision process. This was done in order to assist the second phase with interviews.
The second round of analysis was performed after the interviews. This analysis was carried out with the support of the analysis of the first phase, and Company A’s data. Similarities and connections were searched for, and the theory “filter” presented in section 1 was used to scan the data.

4 RESULTS AND ANALYSIS
This section presents the results of the two case studies. A discussion of findings related to theory will follow. Finally, the most important findings are summarized.

4.1 Empirical findings
This sub-section presents the empirical findings regarding the three different research questions: (1) the companies’ views of the decision-making process; (2) what factors affect the decision-making process?; and (3) how does the level of collaboration affect the decision-making process?

4.1.1 View of the decision-making process
The two selected companies had different views of the decision-making process due to different levels of decision-making maturity. Company A had a product development model based on generic development activities (e.g., idea generation, concept development, etc). They showed no indication of explicit knowledge of the decision-making process e.g. their main focus was on the requirement specification, estimation of project time and value creation for the customer. Little time was spent on gaining process knowledge. Company B had a product development model based on their information processes, value creating activities and areas of responsibilities. Their focus was on handling the information process in an effective and efficient way. Company B had the view that if decisions are taken in a more efficient way (more rapidly), the development project will be more efficient.

4.1.2 Factors affecting the decision-making process
In 2002, Company A had the following situations in various areas of their development projects. The most essential parts from the case study are presented here.

Poor handling of requirements influenced the decision-making process since missing requirements and/or wrong requirements in specifications lead to exceeded project time (cost) and budget. Also the quality/performance targets were frequently not met due to inefficient handling of requirements.

Their lack of experience in product development influenced the decision-making process, resulting in inaccurate estimation of the necessary amount of hours in offers to customers. This resulted in budget and time over-runs.

Organizational aspects influenced the decision-making process when engineers worked in an unplanned environment across multiple projects. The decision-making at multi-project level was lacking, resulting in a poor resource allocation process and stress in the organization. Furthermore, meetings were held with a clear objective of taking critical decisions, but these were rarely achieved in practice.

Management was responsible for the project selection process and thus also the related decisions. The company did not have suitable decision criteria or risk assessment for deciding which type of customer project suited their organization and their competence. This resulted in a project portfolio with a lot of uncertainty. This in turn led to budget over-runs. Furthermore, on project level top management did not fully trust the project personnel, resulting in unnecessary waiting for decisions to be taken.

In 2006, Company A had grown from 25 to 38 employees. The company’s situation in 2006 is presented below:

Handling of requirements had improved since 2002. The company had developed procedures for creating requirement specifications, resulting in more adequate requirements. Improved quality of the requirement specifications supported decision-making.

The product development teams were still to a great extent dependent on top management in product development projects, which delayed decisions and resulted in time over-runs — “It’s a huge problem that we have and I think if we had professional project leaders it would work better because the management would not have to be included quite as much”.

ICED’07/416 6
The product development teams’ knowledge of the development process was not fully utilized. The development teams did not have the authority to adjust the process to different projects or to different targets of projects – “either we use the process model or we don’t”. Nor did the teams have a communicated common goal or strategy from top management for product development projects.

Experience from earlier projects influenced the decision-making process positively because the company now had a well documented experience-based check list of all their major project mishaps, which they used for project risk assessment.

Organizational aspects influenced the decision-making process because no structure for assigning responsibility for decisions in projects was available – “…it works like this - the person doing most of the project work gets to be the project leader”. The company also had difficulties assigning overall responsibility for decisions and decision-making at multi-project level was lacking, resulting in a poor resource allocation process and stress in the organization. Engineers’ time was still spread across multiple projects. Another organizational issue, which had become obvious due to their growth, was that development teams were based on team members who shared the same area of expertise.

Risk management influenced the decision-making process positively. The company now had a better ability to assess risks in projects due to the experience-based check list, but at the same time the list was limited to old risks and no process for assessing potential new risks in projects was available.

Information systems influenced the decision-making process negatively, since decisions took a long time, due to difficulties handling project information. No adequate IT solution for managing product information was available. A web-based project portal had been used in one project but with limited approval from the development team.

Communication influenced the decision-making process positively in the early phases and the teams were good at transferring information from sales to engineering – “In that meeting we try to communicate all that has been said by the customer to the project leader and he can comment on this”. They all sit in the same location so distance is not an issue when communicating internal information. However, the engineers did not communicate continuously with the customers in an efficient way – “I would like to see more contact between developers and customers”. Informal decisions regarding critical issues that were taken outside formal meetings were not always communicated.

Change management influenced the decision-making process negatively since too much time and effort was put in to develop a “complete” requirement specification – “…then come preparations for the development project itself and that is a lot about completing the requirement specification”. Too little attention was spent on the continuous process that dealt with negotiation, balancing and updating requirements.

Project Management influenced the decision-making process negatively. Teams were too dependent on the requirement specification (all answers cannot be included) resulting in over-belief in requirements as a support for taking decisions. Also, formal meetings were not based on good decision-making strategy (handling of: uncertain information, risks associated with alternatives, criteria evolution and consensus) resulting in delays in taking decisions.

Company B had the following situation in 2006/2007. The findings presented below focus on necessary information, area of responsibility, decisions made, and the decision process.

Information systems influenced the decision-making process. There was too much dependency on the existing information system which lacked transparency and made it hard to access the right information. There were no structured processes for how to use the IT systems at different phases of development projects or in different departments. This meant that reaching a decision took a long time due to difficulties in handling information between different parts of the organization. Delays were also due to difficulties in providing the right stakeholders with relevant information during product development (information overload).

Organizational aspects influenced the decision-making process since the company had unclear responsibilities in the communication process and thereby also difficulties in assigning decision-basis
responsibility in the decision-making process. Also no project leader with overall responsibility for the main goal of the development process existed.

Project Management influenced the decision-making process negatively since decision basis was difficult to determine for stakeholders when they were developing decision alternatives and making decisions.

4.1.3 The level of collaboration and its affect on the decision-making process

No distinction in levels of collaboration could be seen in the two cases, which meant that no specific level of co-operation could be related to different factors influencing the decision-making process. The findings were instead generic co-operation factors that influenced the decision-making process. Examples of influences on the decision-making process were:

Lack of joint views of decision basis for projects between Company A and customers influenced the decision-making process negatively and lead to rework, budget and time over-draws. Some projects were as much as 60% over budget and 70% over time because of different beliefs about what should be done. Instead of making decisions based on cooperative information between Company A and customers on evolving problems, they tended to rely on answers in the requirement specification alone.

No adequate model or/and method for customer involvement in critical decisions was available and this influenced the decision-making process in a negative way. This made it difficult for teams to assess when to involve customers in the decision-making process, resulting in wrong decisions because of too low customer involvement.

4.2 Analysis

The organizational environment together with overall priorities of the company, influence how decisions are taken in product development projects. The goal, known opportunities and knowledge of the current situation the company is in, act as part of the basis for the decision-making process.

4.2.1 View of the decision-making process

Company A’s view of the decision-making process was limited and they showed no indication of explicit knowledge of the decision-making process. They had not thought of the product development process as a decision-production system and therefore did not know how to identify the domain of certain problems in their process e.g. time over-draws were not considered to be related to the length of learning and evaluation time before making decisions, but instead the company thought it was a problem of not having exactly specified the requirements. Related to decision-making theory, the company’s view of the decision-making process was rather undeveloped and the ability to handle it in an appropriate way was not possible at that time. Focus on handling the development task time together with the low level of decision-making maturity, gave no opportunity for decision management.

Company B had a better view, or understanding, of the decision-making process. They had the same type of product development model as Company A, but this one also included their product related information processes, value creating activities and areas of responsibilities. Company B had the view that if decisions were taken in a more efficient way (more rapidly), the development project would be more efficient. Company B was successful in producing the right product for their customers (effectiveness) but not at handling product data, so the main issue was increasing efficiency in handling and distributing product data to people making decisions in their product development projects.

4.2.2 Factors affecting the decision-making process

Factors influencing the decision-making process during product development found in the two case studies were divided into ten categories:

(1) Handling of requirements, (2) Experience from earlier projects, (3) Organizational influence, (4) Project management, (5) Top management, (6) Knowledge and information, (7) Risk management, (8) Information systems, (9) Communication, and (10) Change management.
Handling of requirements, change management and communication - When Company A focused on speeding up their development process they looked at incorporating all answers into the requirement specification and on developing an experience-based list of project risks. This resulted in both good and bad results. The focus on the requirement specification made them more successful in gathering the right requirements from the customers but at the same time they did not have a process for requirement changes during development. They relied too much on the requirement list and instead of communicating with the customer when they encountered problems they only looked to the specification, resulting in rework and budget over-runs. The experience-based list of project risks helped them to gradually increase their risk management skills. Company B had an efficient communication process which helped their decision-making process. It enabled decisions to be made despite their lack of transparency in systems handling formal product data.

Experience of projects and Risk management– Company A relied on successfully achieving estimated project time, but their lack of experience resulted in inaccurate estimation of the needed amount of hours in offers to customers, which in turn resulted in budget and time over-runs. This was however improved over time and they learned that different employees’ estimations should be multiplied by different factors to be accurate, e.g. one person estimated two days and the project leader multiplied it by three, so increased experience influenced the decision-making process in a positive way. By documenting their experience of major project mishaps some project risks were avoided. This constituted an important decision basis for the projects and influenced the decision-making positively. Company B had a long experience managing development projects within the same area of products which enabled them to intuitively avoid some project risks. Both their experience and intuition of risks impacted the decision-making process in a positive way. However, both Companies A and B did not have a process for discovering new project risks which lead to decreased efficiency of decision-making in some projects. Also, Company B’s intuition of risks was limited to two, three persons and meant waiting for decisions to be made which decreased efficiency in the decision-making process.

Organizational influence – Integration of different functions was a recognized need at Company A. However, it was difficult for the company to achieve this at the time. More frequent meetings, involving production and the customers, were one of few suggestions for improved integration. Robust decision theory stresses the need for consensus within development groups but Company A had problems handling large meetings, resulting in ineffective handling of relevant decisions between different functions in the organization. Company A was also striving for better defined responsibilities, both at project and company level, and in 2006 the issue of clear responsibility and authority in the organization still remained (“//…the condition for good decision-making is that one has authority to make a decision on the matter – that one has one’s own responsibilities and doesn’t have to run to the manager for all issues that come up…”). Company B suffered from unclear responsibilities in managing and communicating product related information in the product development process. This resulted in a longer lead-time for product development and was fuelled by the fact that they did not have a project leader with overall responsibility for project success. The lack of responsibilities for information and communication impacted on the decision-making in a negative way.

Management and experience – Management at Company A played an important role in project planning, and their ability to choose projects influenced the decision-making process in projects negatively. By choosing some projects which they did not have any pre-experience or knowledge of, the project teams had difficulties in handling the decision-making within the projects. This was also related to assignment of resources when management generically assessed and assigned the same amount of project time to projects. This resulted in a project portfolio with a lot of uncertainty and in turn led to budget overruns. Furthermore, on a project level, top management did not fully trust the project personnel, resulting in unnecessary waiting for decisions to be made and, as Elbanna and Child [36] write, an insecure environment can influence the rationality of decisions made in projects.

Knowledge – Both Company A and B’s knowledge of the development process was not fully utilized since it was not clear to them how to effectively and efficiently use their product development model. This was dependent on management’s knowledge of process implementation and communicated common goals and strategy for product development projects. However, Company B was working
hard to continuously improving their knowledge of the development process, resulting in increased efficiency of the decision-making process.

Information systems - Due to difficulties in handling project information and no adequate IT solution for managing product information, the decision basis at Company A was not of the high quality they strived for. Company and project size called for increased use of information systems, but as Davenport and Prusak wrote, it is vital to organize for exchanges of knowledge and this has a great deal to do with culture and behavior. As such, it is usually meaningless to begin by investing in software [16, 17]. It is therefore important to first consider how to build an organization for learning and knowledge exchange when looking at how to become effective and efficient. In 2006, Company B had, on the contrary, too much dependency on existing information systems which they relied upon to provide a decision-making basis for development teams. There was too much information available to be effective. This in turn influenced the decision-making process in a negative way.

Change management – At Company A, the lack of change management influenced the decision-making process negatively since too little attention was spent on the continuous process that deals with negotiation, balancing and updating requirements. This resulted in a decision basis that was not up-to-date and accurate when team members looked for answers in the requirement specification.

Project management – The growth of Company A resulted in a clear understanding of the need for a project leader with the overall responsibility for the main goal of the project (“We have to have a good project leader, that’s something I think we are suffering from here at Company A”). A leader that is able to make level-headed decisions is vital for project success and Company A suffered by not assigning the overall responsibility to a project leader. In 2006, functions in Company B were not integrated in an effective way, but in 2007 they made some improvements in the information and communication processes, resulting in a more effective handling of product data in the product revision, and new product part development processes. A clear picture of the information process and areas of responsibility for information helped them to communicate in a better manner, resulting in a more efficient decision-making process.

4.2.3 The level of collaboration and its affect on the decision-making process
In both Company A and Company B there were no doubts that the level of collaboration influenced the decision-making process but due to the limited data in the cases no relation between level of co-operation and influencing factors was established.
However, a strong indication of how co-operation affected the decision-making process was shown when the companies expressed the view that their main problem within product development projects was co-operation between departments, customers, and suppliers. This was also confirmed when speaking to other companies in the same geographical area. The problems lie mainly in the shared decision base, in the form of information (product and process information), strategy, and main goal. The increased geographical distance between functions in organizations can lead to difficulties regarding culture and language, thus difficulties in information sharing, which in turn implies repercussions in the decision-making process. However, many of the companies addressed in the region believe in increased opportunities as the product development environment becomes more collaborative. Thus, there are important challenges regarding decision-making in collaborative and distributed product development in the future.

5 DISCUSSION AND CONCLUSIONS
The purpose of this paper was to increase the understanding of decision-making in product development by investigating what the companies’ views of their decision-making process within product development projects are; what they consider to affect the decision-making process during product development projects; and how their level of co-operation affects their decision-making process.

The two companies had different views of the decision-making process due to different levels of decision-making maturity. Company A had difficulties handling co-ordination of development tasks which drew attention away from looking at the underlying decision-making process, while Company B shifted focus towards the decision-making process by looking at the related communication process, and viewed an efficient development process as rapid decision-making. The different views of the
decision-making process within product development projects could possibly be divided into levels of
decision-making maturity but there are no attempts to make such a division in this study. The different
levels of maturity will be investigated in future work.

The ability to distinguish between the communication/information, co-operation and decision-making
processes is shown to be an important issue for successful product development. If a company tries to
“cure” a problem by focusing on the symptom the result will be failure. A clear conclusion that can be
made is that both companies had little or no knowledge of the concept of “decision management,” or
the opportunities for improvement it could represent.

Co-operation put great demand on communication and information management, a situation which
both Companies A and B suffered from. If the division of the different processes (i.e., information,
communication and decision-making) is not clear to the involved parties they tend to have difficulties
identifying the underlying problem, and focus on solving the symptom instead.

The demanding industrial environment of today pushes companies to increase levels of co-operation
(e.g., time pressure and complex products demand higher integration of sub-suppliers), and the authors
of this document argue that further research is needed to identify more extensively the factors
influencing the explicit decision-making process and related decision management in product
development. It is also argued that the conditions for decision-making within distributed product
development should be further investigated. This should be done in order to support industries in
increasing their efficiency in managing different levels of co-operation and collaboration, and
improving decision management in distributed product development. This will also be investigated in
future work.

REFERENCES

Aspects and Parameters Influencing the Outcome of Collaboration. International Conference
Development. International Conference on Engineering Design, ICED’05. Melbourne,
Australia, 2005.
paper to Darmstadt Symposium on designers – The Key to Successful Product Development.
[8] Isaksson, O., Fuxin, F., Jeppsson, P., Johansson, H., Katchaounov, T., Lindeblad, M.,
Haxue, M., Malmqvist, J., Meshihovic, S., Sutinen, K., Svensson, D., and Törln, P.,
Trends in Product Modelling - an ENDREA Perspective. Proceedings of Produktmodeller,
workshop, Tokyo, Japan, 1998.
collaborative design process: a case study. Proceedings of the conference ASME DETC’01,


Contact: Joakim Eriksson
IDP/Mälardalen University
PO POP
P.O. Box 325, Eskilstuna
Sweden
+46 (0)16-153487
+46 (0)16-153610
Joakim.eriksson@mdh.se
Modelling Decision-Making in Complex Product Development

MODELLING DECISION-MAKING IN COMPLEX PRODUCT DEVELOPMENT

J. Eriksson, S. Johnsson and R. Olsson, PhD

Keywords: Decision-making, uncertainty, performance, complex product development, and PDOPM

1. Introduction
The need for shorter lead time, trends with outsourcing, complex product requirements, and shorter product life cycles requires increased knowledge and advanced skills in the design of complex products. The ability to manage such complexities is seen as a competitive advantage for technologically advanced industry, and the global market places greater demands on industry to continuously increase its performance. One challenge today for companies lies in finding the right approach to measuring and continuously improving the current state of a company’s product development process. Integrated product development focuses on the aspect that complex product development puts demands on managing interdependent systems of products and processes with high numbers of elements, thus making it necessary to maintain an overall view in order not to sub-optimise [Malvius 2007]. Integrated product development advocates the integration of work procedures, information management and support tools so the complexity can be managed in an effective and efficient way [Norell 1992]. The task of continuously improving the performance of integrated product development demands the successful management of information, communication, cooperation and decision-making in a context of uncertainty, which is a highly complex task in itself. The research question to which this research ultimately will try to contribute is the following: How can performance in product development be improved? However, in this paper, the research question focused upon is: How can decision-making be modelled in an organizational context, in relation to performance? To be able to manage a complex product development system in an appropriate way, the authors have identified three important aspects of product development. These aspects are decision-making, uncertainty and performance. These aspects form the foundation for the suggested Product Development Organization Performance Model (PDOPM) which is intended to be used by engineering design researchers and, when further developed, product development managers. This initial paper elaborates on the aspect of decision-making and performance.

2. Methodology
This paper is the first in a series of several, aimed at describing the ongoing development of PDOPM. Blessing and Chakrabarti’s [2002] Design Research Methodology (DRM) is the foundation for the research, and this paper is a result of the DRM’s research clarification stage.
To deal with the complexity of product development, a systems theory has been used in this study, in accordance with Arbnor and Bjerke [1997]. Increased complexity stresses the need for models that could be used for teams to develop a shared understanding [Katz and Kahn 1978]. Systems theory is a promising effort to deal with this complexity. There, an understanding of a system cannot be based on knowledge of the parts alone. In systems theory, the whole could be greater than the sum of the parts.
The real leverage in most management situations lies in understanding dynamic complexity, not detail complexity [Senge 1990]. Instead of adopting a rational approach, where only one correct explanation for how data is connected to theory exists, a systems approach is adopted. In it, knowledge is built up from the studied indicator effects. This means that the forces influencing the system are important. Further, the relationships can be either deterministic or stochastic. It is also important to see the processes of change for the system, rather than taking snapshots.

A foundation for this research is several extensive studies on uncertainty management, which resulted in one of the authors’ PhD (see Olsson [2006]). The basis of this research was first developed through a workshop together with senior managers within product development in seven different high-tech industrial companies. The companies are all international companies, based in Sweden. They all have extensive experience in developing complex products within telecommunications, automotive and automation. This formed the initial ideas and problem statements regarding product development, including factors affecting performance. This research then continued with the identification of gaps in literature by conducting reviews within decision-making theory, uncertainty management, and product development performance. A total of twenty semi-structured and open interviews were held at four companies in order to identify the need for change within the management of product development at different levels in the organisations. These results were then incorporated into the PDOPM. Further, the authors’ professional work experience within complex product development was also applied to the development of the PDOPM. The initial results of the research of the PDOPM are presented in this paper.

3. Decision-making in complex product development

What makes a product development process go forward? The fundamental answer is decisions. If no decision is made, the process remains at a halt. So the process may be viewed as a system of decisions that influence each other in a complex way. This view has been discussed in literature in relation to product development organizations and resulted in the concept of Decision-based Design [Herman and Schmidt 2002]. It discusses the gap between design research and practise, which could be bridged by moving from a problem-solving approach to a decision-based approach. Using this view of complex product development as a decision system, the consideration of the whole becomes even more important.

One important question is how this type of decision system is supported. Much attention has been spent on decision-making support systems (DSS) in research to support improvements in decision-making performance in complex product development organizations. Even though the frontier of intelligent decision-making support systems (i-DSS) lies in the ability to incorporate the complex nature of decision-making into computerised analysis and decision-making, the human being is still considered to be the most important part of the systems for making successful decisions [Jatinder et al. 2006]. Studies have shown that designers use their memory to a large extent when retrieving information and tend to seek information and expertise among their colleagues instead of in information systems (documents and reports) [Court et al. 1996, Marsh 1997, Saeema 2000]. It has also been shown that decision-making output quality does not increase if standardization of decision-making procedures and control functions are introduced [Sutcliffe 2001]. This in turn puts even more pressure on supporting and improving the decision-making skill of people in an organisation for increased decision-making performance. The process of learning [Saeema 2000] and evaluation [Nutt 1998] becomes central in order to make high quality decisions in a complex environment. Further, management of aspects such as information, communication, uncertainty, and cooperation has a direct impact on the quality of decisions.

Hansen and Andreasen [2004] and Gidel et al. [2005] argue for a change in designers’ mindsets regarding decision-making and have developed support for amplified cognitive capacity. Both articles present models for better understanding of decision-making in engineering design. Hansen and Andreasen’s approach presents a model of a Decision Node and Decision Map, which has a base in actual decision-making practice. Gidel et al. focus on the connection between decision-making and project management. Both authors support improvements in the human problem-solving capacity in complex situations, i.e. non-programmed decision-making situations. Another example of support of
non-programmed decision-making situations is Saeema’s C-QuARK method [2000], which amplifies a novice engineer’s ability to retrieve information for the basis of design decisions. It seems that focusing on, and supporting, the human decision-making capacity can achieve improvements in design and project performance. The question is which aspects of decision-making are important to focus on to better support product development projects? Cooke-Davis [2002] describes different performance aspects of a project as Project Success and Project Management Success. The aspects relate to success criteria and factors, and depend on which of the following three questions is asked: (1) What factors are critical to project management success?; (2) What factors are critical to success on an individual project?; and (3) What factors lead to consistently successful projects? [Cooke-Davis 2002]. This research aims at developing support for reasoning regarding all three questions.

When reviewing literature of decision-making in product development, including its influencing factors, three categorizations can be distinguished and several authors argue the importance of these categories: Decision-making procedures (activities) [Gidel et al. 2005, Ullman 2006,]; decision-making uncertainty [Busby 2001]; and decision-making environment [Simon 1997].

3.1 Decision-making context and generic factors

Decisions are attempts to create value, and this can only be done through committing resources to actions. However, when committing resources to actions, consequences will occur, and at best, they add to the created value. Thus, it is vital to be able to foresee factors and uncertainties impacting the decision. When studying to what extent these factors are identified and managed when making a decision, it is necessary to use clear definitions of input, output, goal, resources and uncertainty. This research has adopted the viewpoints of O’Donnell and Duffy’s performance framework [O’Donnell and Duffy 2002], based on the IDEFO model [Colquhoun et al. 1993]. An organizational function, activity, or decision has input, output, a goal and resources. If output is compared to goal, effectiveness (\(\pi\)) is determined. If the relation between output and input are compared with used resources, efficiency (\(\eta\)) is determined. However, both effectiveness and efficiency are influenced by uncertainty (\(\mu\)) in decision-making. This could be present as uncertainty in the basis on which a decision is taken, goal or input. If input and goal are compared, it is possible to understand the impact of uncertainty in decisions, actions and consequences. Further, uncertainty can affect the purpose of the decision, i.e. the created value. With the influence of uncertainty, effectiveness and efficiency combined constitute performance (See Figure 1).

3.2 Decision-making and project organisations

In each generic level of an organization, function, activity, or decision can be studied. Each of them is influenced by two kinds of factors: inner factors, e.g. group dynamics; and surrounding factors, e.g. imposed goals. According to Krishnan and Ulrich [2001], generic decisions are made in these levels. When looking at the product strategy level, five generic decisions are made: What is the market and product strategy to maximize probability of economic success?, What portfolio of product opportunities will be pursued?, What is the timing of product development projects?, What assets (e.g. platforms), if any, will be shared across which products?, and which technologies will be employed in the product(s)? When looking at a project management level, five generic decisions are made: What is the relative priority of development objectives?, What is the planned timing and sequence of development activities?, What are the major project milestones and planned prototypes?, What will be the communication mechanisms among team members?, and how will the project be monitored and controlled? Further, when looking at the product activity level, eighteen generic decisions, divided into five categories, are made. The categories are: Concept development, Supply chain design, Product design, Performance testing and validation, and Production ramp-up and launch [Krishnan and Ulrich 2001]. These generic decisions are guided by requirements and constraints, i.e. input, from the project organization. The output at different levels is a subdivision of the goals, requirements and constraints. These are further translated into decisions to serve as goals for activities at the next sub-level. The project organization provides resources to support product strategy, project management, and product activities. It is also suggested that all these generic decisions in Product strategy, Project management, and Product activities have a major impact on all other important decisions within a product.
development process. The question is then how to be able to identify and measure the performance of decisions?

4. A new model of product development organization performance

One of the objectives of developing the PDOPM is to increase the ability to focus on the right aspect of product development performance and to support the development of performance metrics in order to increase decision-making performance over time. During interviews and the workshop, certain aspects have shown to be powerful viewpoints in industry when discussing decision-making performance in a project organizational context. These aspects are: (1) division of performance (metrics, effectiveness and efficiency), (2) uncertainty, and (3) division of decision-making procedure and environment (decision activity and decision-making organization). The categorization at the end of section 3 and these aspects have been incorporated into the PDOPM through the separation of performance into effectiveness and efficiency, uncertainty, decision-making procedure and decision environment.

It is suggested here that an increased awareness and understanding of a simplified whole system, and its relevant influencing factors, will increase product development performance. Hansen and Andreasen [2000] argue that by making people more aware of the decision-making process, their decision-making practice will improve. The intent of the model is to emphasize three identified generic organizational levels. The three generic levels in a project organization have been identified during this research as: (1) Product Strategy, (2) Project Management, and (3) Product Activity. The generic levels are suggested as important in order to understand product development performance. The developed model is primarily intended to provide an understanding of the interaction between performance, uncertainty and decision-making in an organizational system. This will enable researchers as well as product development participants to understand the structure of the decision-making process as part of the development process in an organizational context.

4.1 A decision structure

Hansen and Andreasen [2004] propose that designers, acting in the way they do, may impose negative effects on their designs. Hansen and Andreasen also suggest that designers ought to change their mindset to a more structured approach of decision-making. The process of design is about learning about a problem or an opportunity. Therefore, the process of learning is central and can be incorporated into the approach of Hansen and Andreasen.

One suggestion is the importance of incorporating the learning cycle into the decision activity. This is because the goal and specifying of requirements of the decision impact how designers retrieve and search for information in order to build knowledge. This information, albeit influenced by uncertainty, serves as a basis for the decision itself. Several authors argue the importance of learning in product development, and have proposed models of the learning cycle [Agris & Schön 1978, Kolb 1984]. In this research, the model of IDEO’s method cards [Kelly and Littman 2005] is used to enhance the emphasis on the relationship between the product development process and learning (see Figure 2). The decision-making process, as proposed by Hansen and Andreasen [2004], includes specifying, evaluating, validating, navigating, and unifying. If IDEO’s learning cycle and Hansen and Andreasen’s decision node are combined, the result constitutes a decision activity. The question is how to improve performance in such a decision-making activity?

In a design project, decision activities create a complex network of decisions, and the sheer amount of decisions is too numerous to map. Even if it were possible to map all decision activities, it would be meaningless for reuse in future project due to the innovative, non-repetitive nature of design projects [Gidel et al. 2005]. Studying the nature of decision-making, factors such as the mindset, structuring, input, goal and resources plays a crucial role for performance, and can be illustrated with inspiration from O’Donnell and Duffy’s [2002] performance model (see Figure 1).
If IDEO's learning cycle and Hansen and Andreasen's decision node are combined, they become an illustration of how decision-making relates to effectiveness, efficiency, and uncertainty, as shown in Figure 2. The combination provides a foundation for a discussion regarding surrounding factors, e.g. current knowledge of customer needs, imposed goals for activity performance, given platforms to use for the product, and provided resources for the execution of the activity. Further, it also illustrates how a decision-making activity is impacted by inner factors. Examples of those factors include methods used for creating understanding of the situation, the generation of one or many alternatives, and the approach when selecting an alternative. The combination of the inner and surrounding factors illustrates how a decision-making activity relates to performance. The illustration also provides a foundation for modelling decision-making. It also shows how a decision-making procedure (structure), combined with performance factors, i.e. input, goal, and resources, can be used for reasoning about decision-making activity performance improvements.
4.2 A holistic Product Development Organization Performance Model (PDOPM)

Product development projects are inevitably linked to an organisation. Thus, it is important to create a visual representation of an organisation, linking decision-making and performance in an organizational context. If one lever is pulled to improve an organization, something elsewhere is changed in the system and must therefore be looked upon as a whole in an organizational context [Rummler and Brache 1990]. The performance of product development can be argued to be the accuracy and rate by which an organisation translates a market opportunity into a successful product on the market. This means that if there is a change in the market, performance will be influenced by how accurately and rapidly the company identifies the change and translates it into goal and input for the project organisation, and how accurately and rapidly the project organisation uses it to create a product that corresponds to the market need. The market need is the overall goal for a product-developing organisation. It is also where the final output (product) ultimately is judged. In a business strategy context, market needs are assessed and translated into goal and input to the project organisation. The three identified generic organizational levels are viewed as levels of decision-making activity systems, which interact with one another. They interact by transforming input and goals into output, which in turn serve as goals for sub-levels (See Figure 3). Further, they interact by verification and validation cycles where communication upward in the organisation is enabled. Resources must be provided for the activities to work properly. It is suggested that if these theories are combined in a model of an organisation and its surroundings, performance in product development can be discussed in an organizational context. The suggested model, PDOPM, describes the rationale behind communication, uncertainty and performance (See Figure 3). The market is the primary source when setting the goal for product strategies on a business strategy level. Product strategy includes product portfolio, design briefs and pre-studies, which serve as goals for the project management level. The project management level is responsible for the subversion and communion of the design goal and activity goal to the product activity level. It is also the project management’s responsibility to align design and activity goals with strategic goals in order to achieve coherence in performance. Through the combination of Figure 2 and the PDOPM, it is possible to holistically reason about factors related to communication, uncertainty and product development performance influencing decision-making performance in a complex organizational context.

Figure 3. Product Development Organisation Performance Model (PDOPM).
4.3 Assessing product development performance with PDOPM

Performance in product development is seldom clearly defined and there is often no consensus about what performance is [O’ Donnell and Duffy 2002]. The proposed PDOPM makes it possible to reason about, and assess, efficiency, effectiveness and uncertainty of decision-making within the three generic levels of activity: product strategy, project management and product activities.

*Product strategy effectiveness* describes how the output of the activity meets the defined goal. On the strategy level the goal is to fulfil the business strategy and consequently it is vital that the output correspond to the business strategy. *Product strategy efficiency* is dependent upon making good use of the input and resources in order to create an output. It is vital that the output of the product strategy is delivered in time, at the right quality, to the right people. It is vital in order to transform the identified market opportunity into an initialized project at the right time in order to capture the market window. *Product strategy uncertainty* is strongly related to project portfolio management and the timing of the projects in order to maximize probability of economic success for the company as a whole. A mix of different levels of uncertainty is often sought and the maturity of technology introduced into the projects greatly impacts decision-making uncertainty.

*Project management effectiveness* is e.g. how well the overall needs of a selected customer group, identified at the product strategy level, are translated into a product specification. The identified needs can change over time and is the main focus for the management of the project to fulfil. Effectiveness of the project management is for that reason a measure of how well the project is realizing the dynamic scope of the project. This emphasizes the importance of communication between product management and project management. *Project management efficiency* is related to project planning and is often seen as the main task of project management. Low efficiency in project management activities is shown in high costs and time overruns. Project managers have a propensity to focus on the efficiency aspect during project execution and it is for that reason important to remember that if the effectiveness of the project management activity cannot be assured, everything else is of minor importance. *Project management uncertainty* is strongly related to project planning which, if strictly enforced, will guide the project in a too inflexible way. Uncertainty in, and deviation from, planning of people, budget and time is the nature of projects and is the primary task of a project manager and needs to be managed in a dynamic way during execution of projects.

*Product activity effectiveness* is an important measure and too often forgotten due to unclear goals, directions, or specifications. It is vital that a project manager always focus on the whole of the project in order to communicate a clear and well defined goal for activities. *Product activity efficiency* is defined as the difference between output and input divided by the resources used to realize the output. The resource of time is often seen as the most important at this level but impacts cost in the product life cycle to a great extent and constitute a trade-off between how much time is required to achieve appropriate quality of the decision, or solution, and still make the deadline. *Product activity uncertainty* is crucial to manage and measuring the product activity uncertainty enables discovery of potential problems early in the project when there still is time for changes without risking any substantial costs.

The factor of time is not explicitly shown in the PDOPM, but there is time dependency in the model by the verification and validation loop, see Figure 3. The two feedback loops also represents the communication and learning cycle of the organization. It is also a way to manage activities and the different outputs that is supposed to match the specified goals. The validation loop represents the feedback from the output from project management and it is modelled as an input to the product strategy. The validation represents the possibility for product management to see the progress of the project development project. The verification loop is modelled as the feedback from product activities to project management. By representing it in this way, it shows the possibility for the project manager to view the progress and the output from product activities.
5. Future work of verifying the new model

The presented PDOPM has shown promising initial results in conducted research studies in an industrial setting. It enables the identification of inner, surrounding factors and uncertainties relevant to the management of product development. However, there still remains work to be done, developing the model and an appropriate method to map different aspects of the decision-making process in product development. A literature review and discussions with management and product development project managers at several large companies in Sweden has resulted in the creation of six performance categories to focus on when analyzing a project organization’s decision-making performance. They are: (1) Information management; (2) Communication; (3) Co-operation management; (4) Decision management; (5) Uncertainty management; and (6) Product development performance metrics. The categories will be studied in future research for the development of mapping methods linked to performance, and are not discussed further here. Several case studies are planned to verify the model and for further development.

6. Discussion and conclusion

The need for improvements in product development led the authors to study the combination of three important aspects of the product development process. The aspects are decision-making, uncertainty, and performance within product development. The need for management of such aspects has been shown in industry as well as literature. However, the aspects are rarely combined. To combine them, the authors suggest a change of view of the product development process: they argue for a holistic view of the decision activity system related to product development performance.

The first contribution is an illustration of how decision-making relates to effectiveness, efficiency, and uncertainty. The illustration links performance and uncertainty into a model-based theory of what factors influence decision-making performance. The second contribution is an illustration of a decision activity. It shows the separation of inner and surrounding factors that influence a decision activity. It enables a discussion of which factors influence decision-making as a whole.

In this paper, we have suggested a Product Development Organizational Performance Model, PDOPM, which is intended to support the discussion of decision-making performance in an organizational context. Together with the illustrations, it is possible to separates influencing factors in decision-making into input, goal, resources, organizational levels, communication, and organizational context. It can be used for research studies of product development and support the identification of relevant factors influencing product development performance on different organisational levels in an industrial setting. It can also be used by project managers for understanding and reasoning about product development performance improvements in the context of the whole company.

When we tested PDOPM with empirical studies, PDOPM constituted a powerful model for the identification of factors influencing decision-making in a product development organisation. However, the authors see a need for the further development of the model, which can serve as a basis for the development of a holistic approach to product development process improvements.

References


Joakim Eriksson, Ph.D student
Department of Innovation, Design and Product Development
Section of Product and Process Development
Mälardalen University
P.O. Box 325
E-631 05 Eskilstuna, Sweden
Telephone: +46 16 15 34 87
joakim.eriksson@mdh.se
APPENDED PAPER III

Decision Focused Product Development Process Improvements

Joakim Eriksson and Anette Brannemo. Submitted to Proceedings of ICED’09, 24-27 August 2009, Stanford, CA, USA.
DECISION-FOCUSED PRODUCT DEVELOPMENT
PROCESS IMPROVEMENTS

ABSTRACT
Currently, there is little or no methodology or methods available to “process improvers” in product development which focus on decision-making fundamentals in order to improve the performance of decision-making within the product development process. In order to support product development process improvements, it is important to develop knowledge about how the collaborative decision-making process can be viewed holistically and include its relation to performance aspects. The objective of this research is to investigate what elements characterize a collaborative decision-making system and what enables the management of the system. The research investigates these two aspects through a literature review and a case study at a large Swedish company. A Rich Picture is developed in order to clarify the relationship between fundamental decision-making aspects, performance, the process levels, and the product development organization. The descriptive case study identifies what actors consider to affect collaborative decision-making and exposes the competencies needed in order to manage the collaborative decision-making process.

Keywords: Collaborative decision-making, Product development, and Decision management.

1 INTRODUCTION
The process of developing and producing a product is a knowledge-intense activity influenced by many actors in the organization. It affects many organizational actors as well. A company’s product management of the product development process have been found to be key factors for a product’s success on the market [1]. Today, organizations find themselves in a situation where they need to continuously improve the performance of the product development process in order to stay ahead or even keep up with competitors. Currently, there is little or no methodology or methods available for “process improvers” in product development that focus on decision-making fundamentals in order to improve the performance of decision-making within the product development process. There are methodologies and methods available for the support of different aspects of decisions and the support of specific decisions during product development. Different aspects of decisions, e.g. the generation of alternatives, or criteria evolution, are managed in an isolated manner by methods, and are often used in assistance with an overall methodology, e.g. Ulrich and Eppinger’s product development process model [2]. Specific generic decisions made during product development, e.g. Krishnan and Ulrich [3], are often focused on by the identification of success factors or procedures. For a “process improver,” the vast amount of this sort of knowledge is hard to overlook and to use as a basis for process improvements. This is because of the lack of ability to place different elements of the process, e.g. methods, in a view that relates decision-making to overall organizational performance. During the product development process, most decisions are made in cooperation with other actors who possess different expertise and interests [4]. In order to support product development process improvements, it is important to develop knowledge about how the collaborative decision-making process can be viewed holistically (as a system), including its relations to performance aspects. A holistic view of collaborative decision-making could be used for understanding the current situation in the organization, the preferred future state, and how to achieve it. The first step would be to identify important elements of the product development process, the decision-making process, and the relationships to performance aspects. It is also important to investigate what enables the management of collaborative decision-making in the product development process. Here, the first step would be to investigate what major skills are necessary for an organization to possess in order to control the collaborative decision-making process. These two aspects of process improvements are the main objectives of this research.
1.1 Research Methodology and Methods

Blessing and Chakrabarti’s Design Research Methodology (DRM) is the chosen research methodology for this research, and this paper is a result that lies within the DRM’s prescriptive phase. This research has been carried out through a case study and a study of the related literature.

The methodology of the case study was chosen since it is an effective way of investigating relationships within companies. A case study is described as: “…an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.” [5], (p.13). Data collection was conducted through eight open and semi-structured interviews with seven employees in the case study company. To achieve a wide perspective on the decision-making process, interviews were made in different departments and with people on different levels having dissimilar backgrounds and experiences. The analysis of the different sources was made individually by the authors and then together by the authors. During the case study, the researchers have had full access to the documents connected to the project (e.g. project organization, time schedule, meeting minutes, decision log, administrative documentation, product documentation, and mail). Data have also been collected through active intervention (action research); one of the researchers has been an active participant in the project. Diary keeping from this participant has also been part of the analysis material.

Finally, theoretical studies on product development, decision-making and collaborative decision-making were made before the case study started, as well as afterwards. The theory was used for creating interview questions and analysis filters.

2 THEORETICAL FRAMEWORK

This section introduces the theory used in this research in order to gather relevant data, analysis, and reflection on collaborative decision-making in product development. The chapter is divided into two parts; the process of developing products and its relation to decision performance; and the role of collaborative decision-making in product development. The overall guiding questions during the compiling of the theoretical framework in order to answer research question 1 (in Section 2.2) can be seen in Figure 1.

2.1 The Product Development Process and its Relation to Decision Performance

Ulrich and Eppinger [2] (p.12) define the product development process as “…the sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product”. The documentation of an organization’s product development process may help in identifying opportunities for improvements [2]. All these activities are described on a methodological level and are typical for product development methodology literature. The product development literature that describes in more detail the specific aspects of importance within the methodology stages often focuses on specific decisions or aspects that need to be considered during that specific stage. Specific decisions are e.g. summarized by Krishnan and Ulrich [3], all of which have been extensively researched by the product development research community. Krishnan and Ulrich [3] describe generic product development decisions made at three levels in the organization: strategic, project management and operational. They divide the decisions into those made when setting up a project, and those made during a project. Specific aspects that have been considered important in product development literature are e.g. uncertainty [6], value [7], and decision structuring and planning [4, 8].
Bras and Mistree [8] define the entities of a process as being hierarchical and are:

- **Process**
  - Phases
  - Events (activities)
  - Tasks
  - Decisions

Tasks and decisions require the direct involvement of humans, and phases and events are accomplished by performing tasks and making decisions. The product development process itself is a task for the assigned team to perform. A task may involve different tasks, decisions, phases, and events. Tasks may, or may not, include decisions, e.g. routine work. [8]

The tasks and activities conducted during product development are increasingly dependent on access to accurate information, extraction, and exchange. Further, the decision makers need to identify and include different expertise and perspectives in order to make informed decisions. All this has made the product development process dependent on collaborative decision-making. [4]

Collaborative decision-making is not the study of one perspective; e.g. communication, synthesis, or decision analysis; rather, it is the study of them, and many more, as a whole. It is necessary to view decision-making as a whole, i.e. a system, in order to relate decision-making to product development performance.

But, what is product development performance? As literature shows, that is not an easy question to answer. What we do know is that it is a direct result of our choices during the product development process.

The output of the product development effort needs to be strategically aligned with the overall objectives in order to contribute to the overall performance of the organization. Haffey states: “...organisations must address and overcome situations where departmental functions and activity resources optimise their solutions or outputs to satisfy goals that do not reflect or contribute to the satisfaction of the higher-order goals associated with an organisation. In order to promote the degree of integration attained throughout an organisational system, each individual process, activity, resource and decision must be considered from a more holistic organisational perspective and subsequently be coalesced effectively within the organisation system in order to support the realisation of desired degree of organisational performance.” [9] (p.2).

The role of performance aspects in organizational management has been considered important for a long time [10]. The difficulties in investigating performance in product development are discussed by Kerssens-van Drongelen et al. [11], who identified the aggravating characteristics of the performance measurement problem:

- “accurately isolating the contribution of R&D to company performance from the other business activities”
- “A second problem with measuring the contribution of R&D to the company is that a part of the benefits it generates is hardly quantifiable”
- “A third issue is the problem of matching specific R&D inputs (in terms of money or man-hours) and intermediate outputs (research findings, new technologies, new materials, etc.) with final outcomes”
- “A fourth major measurement problem is the time lag between R&D efforts and their payoffs in the marketplace”
- “It is consequently considered to be difficult to compare and contrast two projects, as they will always be different”
- “The final problem is the acceptance of performance measurement in R&D”

The research area of performance in product development is a relatively new, and there are few studies made focusing on performance in knowledge-intensive product development [12]. Further, the term performance is often used in product development literature without a clear definition [13]. Terminology, including performance, effectiveness, efficiency, and productivity, is misused and used in a confusing way [14]. There are exceptions, e.g. O’Donnell and Duffy [15], and Griffin and Page [16]. They provide a concept of performance which states that “Effectiveness” plus “Efficiency” equals “Performance”. The model is to be interpreted as following: an organizational function, activity, or decision, has input, output, a goal, and resources. If output is compared to goal,
effectiveness ($\pi$) is determined. If the relation between output and input are compared with used resources, efficiency ($\eta$) is determined [13]. However, both effectiveness and efficiency are influenced by uncertainty in decision-making. Further, uncertainty can affect the purpose of the decision, i.e. the created value. Unger and Eppinger [17] categorize sources of uncertainty into: “Technical”, “Market”, “Schedule”, and “Financial”. Uncertainty is often researched within product development through the identification of generic success factors of certain decisions or performance aspects in order to minimize the uncertainty, thereby improving performance. A common approach to the minimization of uncertainty in product development is to ensure that critical success factors are thought of and that reoccurring problems are proactively counteracted. If O’Donnell and Duffy’s performance model [15] is used as a basis, it may be used for the comparison between input and goals, which, in turn, enables the assessment of uncertainties. The extended model can be used for creating a holistic organizational model of the connection between decisions on a strategic and operational level, which enables the assessment of the three different performance aspects (effectiveness, efficiency, and uncertainty) [18], Figure 2.

![Figure 2. The Product Development Organizational Model (PDOPM) [18].](image)

If performance is viewed on a strategic level in relation to a project level in the organization, it is necessary to identify what the higher level is to support the lower with (e.g. objectives and resources) in order for the lower to contribute to the higher level’s objectives. This is not an easy task in itself, and several researchers have tried to bridge the performance gap between levels and departments in organizations, e.g. [16, 19, 20]. The difficulties that present themselves in most, if not all, product development decisions are the tradeoffs between different performance aspects. The performance aspects are often not viewed alike by different levels and departments in organizations which all try to satisfy their objectives. Jankovic [4] (p.15) describes the implications of a modern collaborative industrial environment during the product development process: “In this process, every actor has specific objectives defined for his domain of action. Therefore, the collaborative decision-making is a process where actors have different and often conflicting objectives. Actors in the collaborative decision-making process also have different knowledge concerning the problem as well as different information and points of view.” The classic performance aspects often used are cost, quality, and time. If the objective is to maximize the classical performance aspects and thereby manage their tradeoffs, how does this activity relate to decision-making?

### 2.2 The Role of Collaborative Decision-Making in Product Development

Collaborative decision-making is defined by Jankovic [4]: “Collaborative decision-making is a collective decision-making where different actors have different and often conflicting objectives in the decision-making process.” The role of collaborative decision-making in product development can
therefore be described as the task of collectively reaching an agreement on objectives and using those objectives in order to reach a satisfying decision on performance tradeoffs. The question then is what enables collectively reaching objectives and a satisfying decision on performance tradeoffs.

In product development, many of the activities are linked to e.g. different product requirements. Conventional methods often offer a prescriptive approach to requirements engineering in order to produce the objectives for the system, i.e. what the system should do. However, research indicates that the question of why the system should do it is just as important [21-23]. The “why” question is important in order to consider or justify the incorporation of a requirement. This is especially important for requirements that are not obvious to be important for the customers or users. There are two complementary approaches that are available in producing high-quality requirements during requirement engineering, Goal Modelling and Business Rules Modelling. The goal-oriented approach is used to determine how to realize an ultimate objective, and business rules modelling is used to set the constraints of the requirement engineering work. [24] Goal modelling is an important part of the collaborative decision-making infrastructure which enables all to have an overall system for the objectives on different levels and in different departments in the organization. In collaborative decision-making, the objective is “what the system is to attain” [4] (p.77). Jankovic states: “An objective is a target that is supposed to be attained by one project. This target has three-dimensions: quality, cost and delay.,” and “The objective’s definition in a development project is influenced by the actor’s competences, his personal aspirations and resources that are at the project’s disposal.” [4] (p.78). The objectives, which reflect all the stakeholders’ needs, are in turn interpreted by actors as activities to realize, or goals to attain [4].

According to the Committee on Theoretical Foundations for Decision Making in Engineering Design [25], the quality of decisions also rests upon the systematic and correct framing of the decision situation. In other words, it rests on answering the right question by understanding the issue (what is known), what can be done (alternatives), and what is wanted in the future (preferences). The basis for this framing-model is a prescriptive decision theory, and an assumption is that alternatives already exist. This is common in product development literature. Nonetheless, there are researchers who focus on decision-making before, during, and after alternative generation, e.g. Tang [26]. Often the role of decision-making is to maximize the decision, or to make the best decision.

In Decision Science, there are many different views on what a best decision or good decision is. Tang [26] (p.44) states that: “There is no real consensus on what a good decision is.” However, there is some consensus within the three branches of decision theories. In “Normative” theory, the outcome is not considered to be an evaluative factor to measure. High decision quality is achieved by following rigid rules and fulfilling axioms. What Howard [27] describes is that we can control the decision-making process but not the result or outcome. It is, however, easier to direct the results than the outcome. The result is the implementation of the decided actions and the resources committed, while the outcome is influenced by natural variation and other influencing forces that we cannot oversee or control. Therefore, the outcome is not an appropriate evaluative factor in decision quality [28]. In the “Descriptive” theory, aspects such as difficulty, missed opportunities, and good results, are important factors of decision quality [29]. Nutt [30] developed criteria to evaluate decision quality by considering three measures: measure of “decision value” (impact, merit, and satisfaction), measure of “development time” (decision cycle time and evaluation), and measure of “decision use” (initial adoption, sustained adoption, and full adoption). By evaluating decisions according to these measures, Nutt discovered that half of all decisions fail [30]. In the more pragmatic “Prescriptive” theory, the measure of the decision quality is exemplified by Howard [27], who states six criteria for achieving a high quality decision: (1) a committed decision-maker, (2) a right frame, (3) right alternatives, (4) right information, (5) clear preferences, and (6) right decision procedures. The fulfillment of the last criteria (right decision procedure) is based on the fulfillment of normative axioms and criteria [26].

Collaborative decision-making is an opportunity to increase decision quality through its exchange of information and opinions between actors. This stimulates diversity and richness in alternatives [4]. This is at the same time a source of difficulties. Some of the difficulties are different preferences, values, and judgment, regarding the outcome related to different alternatives. This impacts on how performance tradeoffs are managed throughout the decision-making process and in turn the decision quality.
2.3 Analysis of the literature – A Collaborative Decision-Making System

In order to investigate what elements a collaborative decision-making system may include, a research question was formulated: what elements characterize a collaborative decision-making system? Literature was reviewed and compared with results obtained from the DRM’s Research Clarification Phase conducted earlier in the research. Also, as an additional source, discussions with an industrial product development manager were an input to this work. This was done to verify the findings from the literature and to relate it to an actual industrial need.

The literature points to nine elements of great importance for a collaborative decision-making system. These are: (1) the development process, (2) the structure of the process, (3) the performance of decisions, (4) the framing of decisions, (5) the organization, (6) the communication in order to achieve objectives, goals, alternatives and to manage tradeoffs, (7) the individual actors and their preferences, objectives, and judgment, (8) the methods/tools, and (9) the product/delivery/output. In order to clarify the connection between decision-making, performance of decision-making, and the product development organization, a “Rich Picture” together with the Product Development Organizational Performance Model (Figure 2) was developed. When combining the two, they show how it is possible to view product development as a collaborative decision-making system and include its influencing aspects (see Figure 3).

![Figure 3. The Collaborative Decision-Making System.](image)

3 CASE STUDY

The case study company competes within mechanical industry. The case study company has a department responsible for securing all new development projects within the company. This department is also responsible for securing the progress of all new development projects, managing the deliveries and costs in the right time with expected quality, and driving and improving the work with development and project models. The project leader from this department is responsible for the decisions in the project and manages a cross-functional engineering team to be able to reach the project goals. A single decision was investigated by first mapping activities considered by actors to be important for the decision-making process (see Figure 4).
A research question was stated in order to enhance the knowledge of collaborative decision-making behaviour in product development: what factors do actors perceive to effect a collaborative decision in product development and how does it relate to decision-making literature? The open questions were asked to the interviewees about e.g. the procedure of the decision process, influencing factors, strengths and weaknesses, and involved actors. The Collaborative decision-Making System, in cooperation with decision and product development literature, was the basis for the analysis.

3.1 Empirical Findings
Interviewees responded to the open questions about the perceived influencing factors of the collaborative decision-making process. The empirical findings in the descriptive case study showed that actors perceive influencing factors as a diverse range of factors on different levels (e.g. decision-making responsibilities) and processes (e.g. requirement management). Thirty-seven different factors related to their decision-making were considered to have influenced the specific decision. The factors were: Functional integration, Processes, Decision criteria, Decision methods, Structures, Decision procedure, Decision culture, Decision premises, Information, Coordination, Goals, Uncertainty, Stakeholders, Change management, Requirement management, Customer involvement, Objective creep, Strategies, An overview, Planning and control, Politics, Information flows, Consequence analysis, Resource management, Roles, Scope, Tradeoffs, Rationality, Authority, Market need, Competitors, Manning, Intuition, Alternatives, Constraints, and Commitment.

The factors were related to three generic aspects of collaborative decision-making: Environment and structures, enablers, and procedures. A short description of some of the factors follows. Goals for the decision activity were considered to have been a weak point in the decision-making process. An example of a statement is: “They (the main project group) work a long time and want at the same time that we work at full speed when they haven’t provided the goals yet. We should let the early phases take the time they need and work only after having decided (on the goals) instead of fooling around with the requirements.”

Alternatives were described as an activity, but without stating how they were developed. The interviewees described that they delivered four alternatives, but just stated that it was a matter of collecting available information, determining costs, categorizing, and summarizing. No explanations of how alternatives were first developed were described. “We develop alternatives, check the tradeoffs, and pass it on for final choice.”

Decision-making procedures were often described on a generic level. They were described as a part of a series of activities. No description of a full decision procedure was given. An example of a statement is: “When one is to investigate consequences within the whole (of the project) and in detail, the first
thing is to bring them up (the alternatives) in the project team so all get to go home and look at the impacts they have on their specific area, and bring the conclusions back. Otherwise, it is easy to miss something that will impact on a certain aspect.”

Criteria for decisions were described as cost, time, and quality, but also risk tolerance. Two examples of statements are: "We checked the cost and necessary resources and took it to the steering committee, who said that it was too much money right now and also that it was too much risk with the “new content.””

And;

“The time plan is the most obvious guiding means also when it comes to goals. That is, the goals and requirements we put up are relevant as long as we can reach them within the time frame set in the project.”

Consequence analysis was described as a way to understand consequences, as well as a means to influence the steering committee’s direction with old, and new, decisions. “My part was to calculate what the cost would be in the end for the customer regarding the alternatives. ... What we also wanted to show with the calculations was that we could deliver a higher value for the customer without implementing the decided direction that was being investigated.”

Uncertainty (in knowledge) was considered to be a great problem in the decision and in general. An example of a statement is: "We make decisions with great uncertainties but act as if we are sure. I think that the decisions we are uncertain about, and where we risk taking decisions on uncertain grounds, we get to regret in the form of quality deficiencies later on in the process and thereby lose market shares and all that follows with competitive advantage and profits.”

Tradeoffs were not mentioned explicitly. However, they were mentioned as an argumentation about market needs, investment costs, uncertainty in assessed production volumes, and uncertainty of the value chain. That argumentation was central to all actors involved in the decision, without the interviewees mentioning the word “tradeoffs” once.

Information (uncertainty) was also described as a barrier to efficient communication, and understanding between actors. It was stated that information was hard to understand in regard to the actor’s own point of interest. Also, the different levels in the organization treated information certainty in different ways. One example is: "Depending on where we are in a project, in relation to the development model, information means different things. That fact can definitely be an explanation for why the management level in the organization writes (early developed) things in stone too early.”

4 ANALYSIS AND RESULTS

Out of the 37 factors, there were eight factors that directly related to decision-making literature (which was chosen to be presented in the previous section) which was chosen through a comparison with the Collaborative Decision-Making System, and a list of main aspects of collaborative decision-making theory. Two of the factors were mentioned between eight and nine times, three were mentioned between six and seven times, and three was mentioned less than four times. The eight main factors that directly related to decision-making literature were;

- Goals (management of goals on different levels in the organisation)
- Alternatives (alternative generation and selection)
- Decision-making procedures (the steps the actors took to carry out decisions)
- Criteria (in order to select alternatives)
- Consequence analysis (decision analysis)
- Uncertainty (of information, environment, and the decision situation)
- Tradeoffs (between performance aspects of the organisation and the product)
- Information (uncertainty, and communication)

These main factors were compared to decision-making and product development literature, and relationships were sought. The analysis was conducted by categorizing findings into elements and factors of the collaborative decision-making process. This resulted in three findings: (1), the main elements that constitute the context of actors in product development decision-making, (2) competencies needed to manage the collaborative decision-making process in a product development organization, and (3) elements important for future research work. These three findings are described below.
4.1 Actors in the Middle of the Elements

The actors within the collaborative decision-making process identified a few main elements for them to manage and use during the process. They described elements to surround them and put themselves in the middle of the context. The main elements identified are the process itself, the methods to use, the management of requirements, and everything needed in order to develop a product. What has been shown in the analysis is that the actors use strategies and tactics, e.g. “We develop alternatives, check the tradeoffs, and pass it on for final choice”, to make collaborative decisions. They are not always aware of what strategy they are using and may sometimes, or quite often, only focus on a small part of the decision. This makes the whole of the process unattended, e.g. "We make decisions with great uncertainties but act as if we are sure...".

The actors would benefit from an increased awareness of the relationship between different parts of the decision and overall objectives and performance aspects in order to manage the tradeoffs. This could be done with a further development of the Collaborative Decision-Making System in the specific context of the organization. Further, an increased awareness of the decision-making strategy employed would increase the possibility of reaching a decision that is good enough. A model of the relationship between all these elements can be developed, and is seen in Figure 5.

![Figure 5. Actors in the middle of the overall elements.](image)

4.2 Different Competencies for Collaborative Decision-Making

The identified elements and influencing factors of collaborative decision-making can be summarized by relating them to overall aspects of the task of collectively reaching an agreement on objectives and using those objectives in order to reach a satisfying decision on performance tradeoffs. In order to achieve this task, there are three overall factors of great importance identified in the literature and the case study that can be used: (1) the ability to frame a decision situation, (2) the procedure used for reaching the decision, and (3) the methods used during the procedure in order to reach a decision.

The ability to frame a decision situation depends on the availability of expertise and information that enables the understanding of what is needed to know about the specific situation, what can be done within the limitations of the situation, and what the preferred outcome of the situation is.

The procedure used for reaching the decision is often a procedure defined on an activity or task level of the process. However, if a decision level is investigated, the enabling of the actors’ understanding of their preferred behaviour (steps taken), their common preferences, and their role in the decision situation enable a successful execution of the procedure.

The decision methods used during the procedure in order to reach a decision are of great importance. They include organizational rules, techniques, and infrastructure. Rules often seem to be a part of the decision-making culture and are not written down; rather, they are fostered through cultural behaviour of managers. Techniques are different ways of investigating tradeoffs or aspects of the decision situation. In product development, these are often QFD, FTA, or similar methods. The infrastructure for the decision-making process in a product development organization is often made up of the organizational map, IT-systems, and formal and informal networks of actors.

These overall aspects are therefore a categorization of the skills or competencies needed in organizations in order to manage the collaborative decision-making process, and can be used for creating a model (see Figure 6).
4.3 Different Element of Importance for Future Work

The elements of collaborative decision-making identified in the Collaborative Decision-Making System, the eight decision-making factors, and the actor in the middle model, are divided into two distinct different categories: individual actors and collaborating actors (collaboration). This is done because actors bring different aspects into the collaborative decision-making process as individuals and as collaborators. Individual actors bring e.g. the aspects of preferences, cognition, and competencies into the process, while the collaboration brings e.g. the aspect of decision-making culture, strategies, tactics, and methods into the process.

These aspects all have important influences on the collaborative decision-making process, but not all are included in the decision-making or product development literature. This may be because of their generic nature, e.g. decision-making culture, strategies, and tactics. These aspects seem to be of great importance for the actors in product development and could be a part of Decision Management, which will be future work in this research.

5 CONCLUSIONS AND DISCUSSION

An objective of this research was to investigate what elements characterize a collaborative decision-making system. The research has investigated what these elements are through a literature review and a case study. A Rich Picture was developed, including the PDOPM (Figure 2), in order to clarify the relationship between fundamental decision-making aspects, performance, the process levels, and the product development organization, thereby creating the Collaborative Decision-Making System (Figure 3).

The descriptive case study identified what actors consider to affect collaborative decision-making and exposed the need for a shared view of fundamental collaborative decision aspects, their overall relations (the system), and an understanding of the competencies needed in order to manage the collaborative decision-making process. A competencies model was presented (Figure 6), and is intended to summarize the understanding of what aspects are needed to manage in order to ensure effective, and efficient, collaborative decision-making in a product development context.

What these aspects of collaborative decision-making showed was that there is great potential for identifying process improvements by observing decision-making practices in relation to fundamental decision-making theory. The fundamental decision-making aspects act as a basis for understanding the root cause of different difficulties and connect the aspects to a process, from a fundamental level to a strategic level in the organization. The aspects can be said to relate to individuals or a group of actors involved in a process, and include descriptive aspects of decision-making as well as prescriptive.
When comparing the empirical findings with decision theory, it is shown that there is a need for certain competencies in the company in order to manage these aspects. The competencies serve as a basis for successfully identifying an opportunity for a decision, framing the decision, developing and executing a strategy for making the decision, and making the decision, including the follow-up. The competencies consider the most fundamental aspects of collaborative decision-making that need to be considered as a whole when introducing efforts to improve collaborative decision-making.

There are certain aspects of collaborative decision-making in product development that need to be further researched. They include the aspect of decision-making culture, strategies, and tactics.

The authors of this paper would like to show their gratitude to the case company which provided the opportunity to explore the research questions within the industrial context of product development. Finally, the authors would also like to thank the different people who have contributed to the discussions and thoughts regarding the research results.

REFERENCES


