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DECISION-FOCUSED PRODUCT DEVELOPMENT PROCESS IMPROVEMENTS

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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.

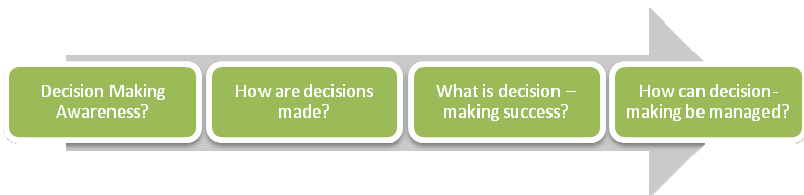

Figure 1. Overall questions during the compiling of the state of the art.

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: *"…organizations 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 organization. In order to promote the degree of integration attained throughout an organizational system, each individual process, activity, resource and decision must be considered from a more holistic organizational perspective and subsequently be coalesced effectively within the organization system in order to support the realisation of desired degree of organizational 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-intense 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 (π) is determined. If the relation between output and input are compared with used resources, efficiency (η) 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.

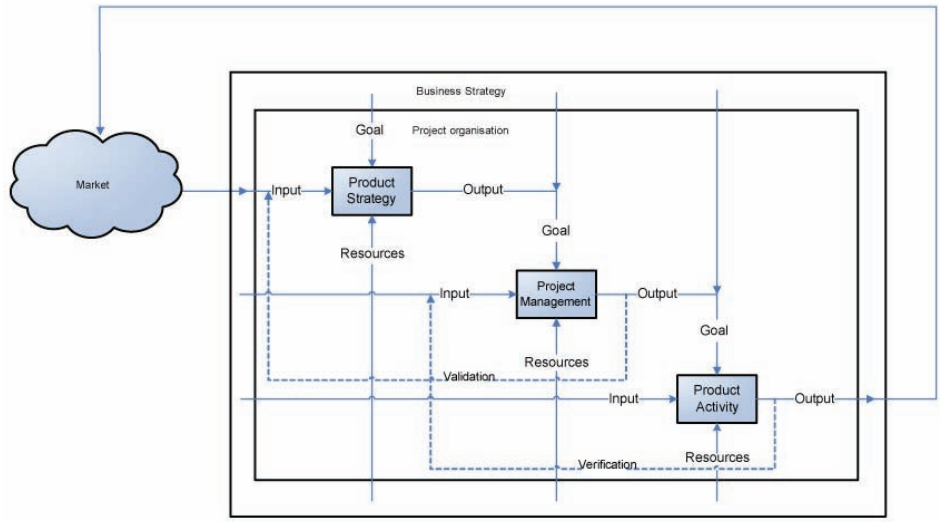

Figure 2. The Product Development Organizational Model (PDOPM) [18].

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 fulfilment of the last criteria (right decision procedure) is based on the fulfilment 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).

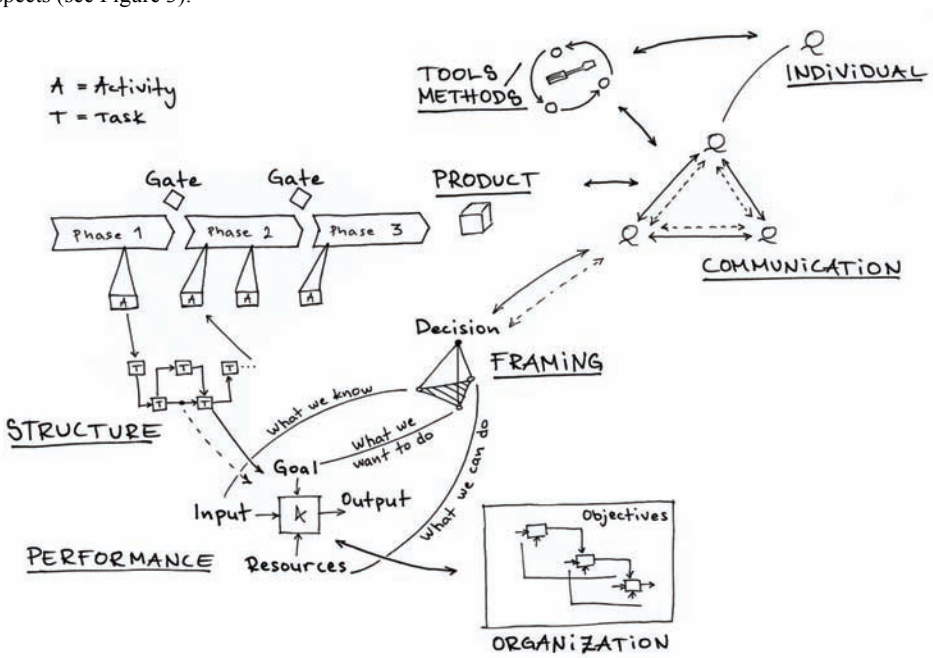

Figure 3. The Collaborative Decision-Making System.

3 CASE STUDY

The case study company competes within mechanical industry. The number of employees is approximately 1,200, and 70% work in the manufacturing department. 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).

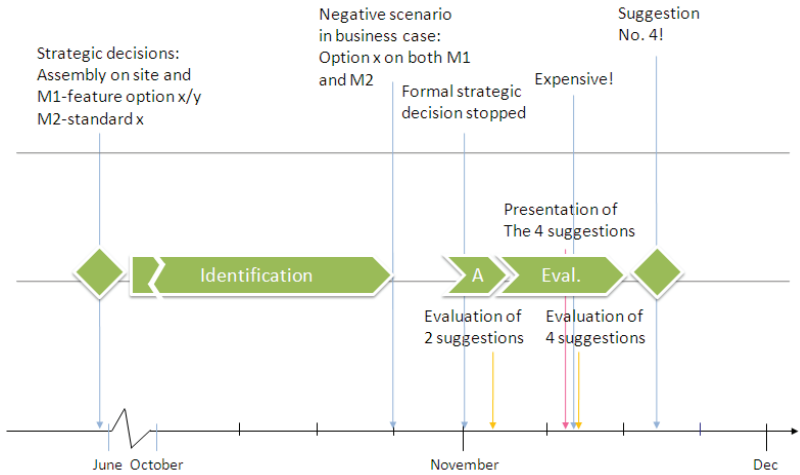

Figure 4. The identified important activities of the collaborative decision-making process.

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 the37 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 organization)*
- *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 organization 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 knowledge/expertise needed in order to develop a product. What has been shown in the analysis is that the actors use strategies, e.g. *"We develop alternatives, check the tradeoffs, and pass it on for final choice",* to make collaborative decisions. Strategies are the patttern by which the actors proceed through the decison-making process. They are not always aware of or plan for 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 also use tactics in order to deal with issues that arise during the decision-making process, e.g. the communication pattern in order to resolve tradeoffs. Tactics are the the ways (communication and methods) by which actors resolve issues in the decision-making process.

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 tactics. 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.

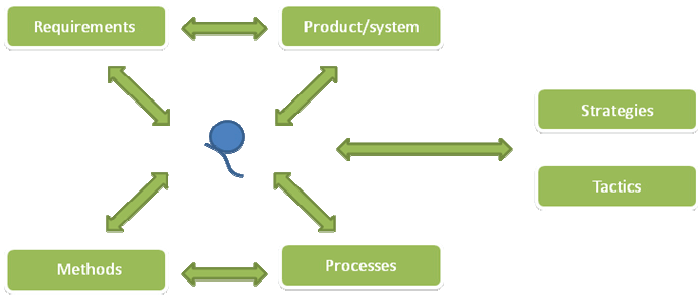

Figure 5. Actors in the middle of the overall elements.

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).

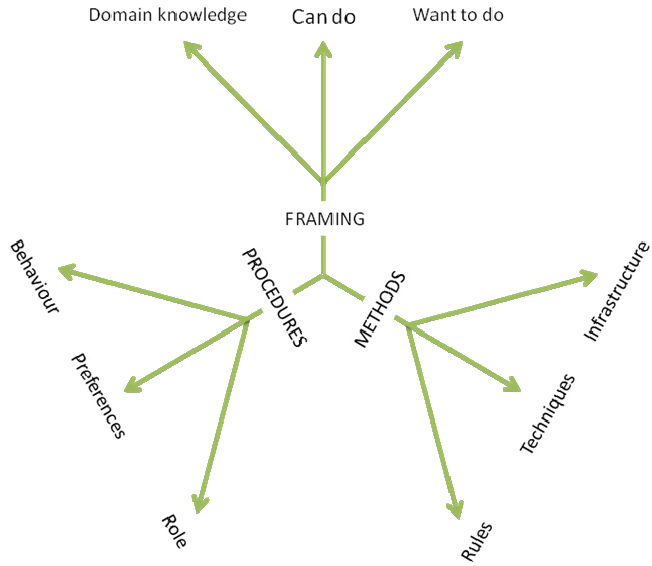

Figure 6. Competencies for the management of collaborative decision-making in product development.

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.

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REFERENCES

[1] Brown, R., *Group Processes*. 2000, Malden, Massachusetts, USA: Blackwell Publishers.
[2] Ulrich, K.T. and S.D. Eppinger, *Product Design and Development*. 4 Rev Ed. 2008, New York: McGraw Hill Higher Education.
[3] Krishnan, V. and K.T. Ulrich, *Product Development Decisions: A Review of the Literature.* Management Science, 2001. **47**(1): pp. 1-21.
[4] Jankovic, M., *Prise des decisions collaboratives dans le processus de conception de nouveaux produits (In French). Application a l'automobile.*, in *Laboratoire de Génie Industriel*. 2006, École Centrale des Arts et Manufactures Paris.
[5] Yin, K.R., *Case Study Research – Design and Methods*. Second ed. 1994, Thousand Oaks, CA: Sage Publications, Ltd.
[6] Lipshitz, R. and O. Strauss, *Coping with Uncertainty: A Naturalistic Decision-Making Analysis.* Organizational Behaviour and Human Decision Processes, 1997. **69**(2): pp. 149–163.
[7] Browning, T.R., et al. *Complex System Product Development: Adding Value by Creating Information and Reducing Risk*. in *Proceedings of the Tenth Annual International Symposium of INCOSE*. 2000. Minneapolis, Minnesota, USA.
[8] Bras, B. and F. Mistree, *Designing Design Processes in Decision-Based Concurrent Engineering.* SAE Transactions, Journal of Materials & Manufacturing, 1991. **100**: p. 8.
[9] Haffey, M.K.D., *An Approach, Insights and Methodology for Performance Improvement through Process Activity Management*, in *Department of Design, Manufacture and Engineering Management*. 2007, University of Strathclyde: Glasgow. p. 578.
[10] Kennerley, M. and A. Neely, *A Framework of the Factors Affecting the Evolution of Performance Measurement Systems.* International Journal of Operations & Production Management, 2002. **22**: pp. 1222-1245.
[11] Kerssens-van Drongelen, I.C., B. Nixon, and A. Pearson, *Performance Measurement in Industrial R&D.* International Journal of Management Reviews, 2000. **2**: pp. 111-143.
[12] Johnsson, S., *Performance and Performance Measurements in Complex Product Development*. 2008, Mälardalen University: Västerås, Sweden.
[13] O'Donnell, F.J. and A.H.B. Duffy, *Modelling Design Development Performance.* International Journal of Operations & Production Management, 2002. **22**(11).
[14] Tangen, S., *Evaluation and Revision of Performance Measurement Systems*, in *Department of Production Engineering*. 2004, KTH: Stockholm.
[15] O'Donnell, F. and A.H.B. Duffy, *Design Performance*. 2005, London: Springer-Verlag.
[16] Griffin, A. and A.L. Page, *An Interim Report on Measuring Product Development Success and*

Failure. The Journal of Product Innovation Management, 1993. **10**: pp. 291-308.
[17] Unger, D.W. and S.D. Eppinger, *Improving Product Development Processes to Manage Development Risk.* MIT Sloan Working Paper 4568-06, 2006.
[18] Eriksson, J., S. Johnsson, and R. Olsson, *Modelling Decision-making in Complex Product Development*, in *International Design Conference - Design 2008*. 2008: Dubrovnik, Croatia.
[19] Munns, A.K. and B.F. Bjeirmi, *The Role of Project Management in Achieving Project Success.* International Journal of Project Management, 1996. **14**(2): p. 7.
[20] Shenhar, A.J., et al., *Project Success: A Multidimensional Strategic Concept.* Long Range Planning, 2001. **34**: p. 26.
[21] Loucopoulos, P. and V. Kavakli, *Enterprise Modelling and the Technological Approach to Requirements Engineering.* Intelligent and cooperative information systems, 1995. **4**(1): p. 34.
[22] Yu, E., *Towards Modelling and Reasoning Support for Early Phase Requirements Engineering*, in *RE '97*. 1997: Annapolis, MD, USA.
[23] Yu, E. and J. Mylopoulos, *Why Goal-oriented Requirements Engineering*, in *REFSQ '98*. 1998: Pisa, Italy.
[24] Loucopoulos, P., *Requirements Engineering*, in *Design Process Improvement - A Review of Current Practice*, J. Clarkson and C. Eckert, Editors. 2005, Springer-Verlag: London.
[25] Committee on Theoretical Foundations for Decision Making in Engineering Design, N.R.C., USA, *Theoretical Foundations for Decision Making in Product Development.* National Academy Press, 2001.
[26] Tang, V., *Corporate Decision Analysis*, in *Engineering Systems*. 2006, MIT.
[27] Howard, R.A., *Heathens, Heretics, and Cults: The Religious Spectrum of Decision Aiding.* Interfaces, 1992. **22**(6): p. 15-27.
[28] Hazelrigg, G.A., *Systems Engineering: An Approach to Information-based Design*. 1996, Upper Saddle River, NJ, USA: Prentice-Hall, Inc.
[29] Yates, J.F., *Decision Management*. 2003: John Wiley And Sons Ltd.
[30] Nutt, P.C., *Why Decisions Fail: Avoiding the Blunders and Traps That Lead to Debacles*. 2002: Berrett-Koehler, USA.

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