INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED15
27-30 JULY 2015, POLITECNICO DI MILANO, ITALY

A METHODICAL APPROACH TO MODEL AND MAP INTERCONNECTED DECISION MAKING SITUATIONS AND THEIR CONSEQUENCES

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Abstract

As products become more and more complex and have to be developed in less time, decision makers are facing the need to achieve good decisions efficiently. While some of the decision making processes are easy to undergo and their respective consequences can be identified with precision, other decision situations are characterized by complex steps and by consequences which are hard to predict.
Therefore, the objective of this paper is to identify, analyze and evaluate conflicting decision making situations whose consequences are difficult to predict. The goal is to elaborate on a methodology in order to categorize and structure decision making situations and their respective consequences. This methodology is intended to support decision makers in evaluating decision making situations with regard to their interconnectivity and potential consequences.
Future steps are the application of the overall methodology in a case study and its improvement due to the lessons learned.

Keywords: Decision making, Decision making process, Decision consequences, Design methods, Process modelling

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Please cite this paper as:
Surnames, Initials: *Title of paper*. In: Proceedings of the 20th International Conference on Engineering Design (ICED15), Vol. nn: Title of Volume, Milan, Italy, 27.-30.07.2015

1 INTRODUCTION

As products become more and more complex and have to be developed in less time, decision makers are facing the need to reach good decisions efficiently. While some of the decision making (DM) processes are easy to undergo and their respective consequences can be identified with precision, other decision situations are characterized by complex steps and by consequences which are hard to predict (Jupp et al. 2009). Bennet and Bennet (2008) state that, with increasing complexity, consequences are getting harder to anticipate which leads to the need to change and improve DM processes.

1.1 Problem description and motivation

Increasing complexity leads to a distribution of control as single decision units may lack of the cognitive capacity to embody the problem in its entirety (Brehmer, 1991). Consequently, the efforts and collaboration of lots of contributors from various disciplines is required for the development of complex engineering products. According to Yassine (2004), this results in complex relationships among both people and tasks. For this, the assumption can be made, that the design of a complex product represents a complex goal that has to be achieved. Dörner (1989) describes complex goals from a psychological perspective as being goals which are formulated in a generic way, implying various sub-goals that are not necessarily defined from the start. Sub-goals have to be achieved to reach a solution for one complex goal. A complex goal could be the further development of an existent middle class car, for example, to make it more attractive. Increasing attractiveness is not a well-defined goal. However, this objective may include a plurality of sub-goals. These partial objectives have to be defined and possible interrelations have to be evaluated to formulate concrete sub-goals, which should lead to the creation of one common solution of the problem. Attractiveness could be determined by the exterior and interior design and the power and fuel consumption of the engine.

All these aspects could result in differentiated sub-goals that need to be formulated and solved in order to achieve the overall goal. Even though each of these sub-goals could potentially be solved by other persons, each one has to contribute to achieve the overall objective. Some sub-goals are likely to depend on each other. Hence, a decision maker does not only need to make decisions serving his own goals, but has also to consider the effects of a decision on all the further steps of the development. So, the problem is to identify these potentially critical situations. Once identified, the decision situation needs to be analysed to understand how negative consequences can be reduced. Ehrlenspiel et al. (2007) explains that decisions during the product development process (PDP) have far reaching consequences and therefore thoughtful DM is particularly important during the PDP.

The complexity in DM processes and situations can be managed by distributing tasks among an increasing number of specialists. These tasks represent the stated sub-goals. However, in many cases, sub-goals affect and contradict each other (Dörner, 1989). In order to reach the overall goal, mutually influencing aspects have to be considered and adjusted. The problem here is that the apportioned sub-goals can potentially contradict each other and trigger unwanted consequences, which might remain unnoticed until they appear, and prevent from reaching the stated overall goal.

1.2 Research objectives

The objective of this paper is to identify, analyse and evaluate conflicting DM situations whose consequences are difficult to predict. The goal is to elaborate on a methodology in order to categorize and structure DM situations and their respective (potentially unwanted) consequences. This methodology is intended to support decision makers in evaluating DM situations with regard to their interconnectivity and potential consequences. The overall focus is the domain of product development, which includes the whole process from transforming a market opportunity (e.g. customer wishes) into a product ready to sell (Krishnan and Ulrich, 2001).

2 ANALYSIS OF RELEVANT APPROACHES AND RELATED WORK

Some existing approaches regarding the overall objective is briefly analysed and critically evaluated in this section. Gaps will be identified that have to be closed in order to set-up a comprehensive methodology. This methodology will combine and modify some of these approaches, to analyse decision situations and their interrelations in regard to their consequences for critical situations.

2.1 Mapping decision making situations onto a development process

The sub-goal of mapping DM situations onto a PDP is to provide a logical overview onto how decisions are linked throughout the product life cycle. To understand where decisions are made and how these decisions interact, a map can be used according to the model explained in Ottosson (2006). This can be complemented with the distribution of DM situations (Vajna & Burchardt 1998). The idea is to project the distributed network of decisions onto the development map by Ottosson (2006). The benefit of this approach is the potential to indicate, (i) the amount of involvement, measured in time or money, which is then transferred to relative measures for each point in time of the process, (ii) the following decisions affected as well as (iii) the relative involvement of the different functional departments in respect to the progress of the design process. However, the distribution of decision situations that is projected onto the PDP remains unstructured and exists only as an idea. Consequently, a structured method is needed to map decision situations within a PDP. This approach should allow to understand which decisions are executed at which point of time during the PDP as well as which department is supposed to execute which decision. As PDPs are likely to follow similar patterns, models can be build which represent the development process in a structured and generic way.

The framework for decision-based engineering design, originally developed by Hazelrigg (1998) and further developed by Chen et al. (2013), aims at optimizing the target product while taking into account certain factors and criteria. The approach provides a helpful framework for considering different perspectives onto the design process. The entities which are provided by this framework indicate actions undergone in the PDP which can be assigned to different functions. The arrows used in the framework indicate relationships between entities. These entities are expressed in parameters influencing the product design. The events, illustrated by dotted boxes, indicate actions which lead to parameters. Every action, besides the discrete choice analysis, also indicates a starting point, at which the whole process can be triggered. The process can be accordingly started with an analysis of customer preferences, the formulation of corporate interests or the formulation of design variants. The process will end when an acceptable state is reached, which will certainly be visible when calculating the expected utility. An end is also imaginable during the steps design options, engineering attributes and customer's desired attributes for the case that during none of the mentioned steps, a potential enhancement of the utility is possible. Within this model, interrelations between decision situations can be stated clearly with the help of arrows and variables.

2.2 Characterization method for decision making situations

The characterization of decision situations can be done with the help of various dimensions. The characterization is intended to help estimating the range of consequences and the influence onto further decisions. By characterizing a decision situation, estimations can be given of how much time and resources are needed to come to an acceptable solution or decision. Different approaches exist to characterize decision situations. Most approaches are descended from non-product development related sources. Two of the most relevant approaches for this work are introduced.

The characterization by Grünig and Kühn (2013) has an organizational background, compiling nine dimensions of decision situations. These dimensions are: degree of difficulty, problem structure, kind of the decision, character of the decision, dependency on other decisions, layer of the decision, type of decision maker, number of persuaded objectives, predictability of outcomes. Parts of this compilation consist of dimensions and characteristics which have been proposed by various other authors.

In contrast to Grünig and Kühn (2013), Orasanu et al. (1993) research DM from an overall perspective, regarding decisions made in a wide range of backgrounds focusing on naturalistic DM. Naturalistic DM means that real life situations are considered rather than theoretical experiments (or experiments in the laboratory) with widely restricted and predefined attributes that describe the situation. Naturalistic DM is taken into consideration in order to provide a complement to the more theoretical approach by Grünig and Kühn (2013). The characterization contains eight dimensions or characteristics which describe DM situations. The characterization by Orasanu et al. (1993) partly overlaps with the dimensions by Grünig & Kühn (2013).

The stated dimensions from different backgrounds have to be put together. Then, their adaptability onto DM situations in the PDP has to be validated. Due to different backgrounds, the authors tend to use different expressions when referring to the various aspects of DM. Therefore, the expressions used have to be evaluated and a consistent terminology has to be defined. While a broad range of characteristics is considered to define a decision situation, not all are expected to be equally important. In order to elaborate a rating method of DM situations, specific weights have to be assigned to each dimension for every DM situation. In order to obtain a method which is supposed to be used to check which situations are considered critical, a framework needs to be established which provides a structured logic of how to rate decision situations.

2.3 Set-up of a structured decision making process

Several approaches of different authors describe differing aspects of DM in theory. While many decisions are trivial and can be made ad hoc, complex decisions require structured approaches to accomplish a solution (Jupp et al., 2009). Simon (1960) points out that "all the images falsify decision by focusing on its final moment. All of them ignore the whole lengthy, complex process of alerting, exploring, and analysing that precede that final moment". Approaches that can be used to depict the decision process are proposed by Chen et al. (2013), Grünig & Kühn (2013), Hansen & Ahmed (2002), Hansen & Andreasen (2004), Hazelrigg (1998), Höhne (2004), Jupp et al. (2009), Pahl et al. (2007), Schneeweiss (2003) and Ullman (2001).

Regarding the overall goal, evaluating decision situations in regard to their consequential effects onto further situations, some aspects have to be regarded. First, the trigger that initiates the decision process has to be considered in order to understand the origin of the decision. Furthermore, depicting the sequence of steps that are undergone during a decision process helps to structure and understand the decision process in detail. The above mentioned logic by Dörner states that complex problems have to be broken down into easier ones to solve sub-problems in order to reach the initial goal. This is assumed to be not only applicable to the process of solving complex problems, but also to the process of analysing these problems. Within these steps, potential links to outside participants have to be drawn. These additional links are important because decision situations are not evaluated in isolation but in regard to their environment, especially considering the respective consequences. This is because the execution of a decision will seldom only have one single intended consequence, but will rather be followed by a composition of intended and unintended consequences. These links include criteria restricting the range of possible solutions, information input if needed by the decision maker as well as links to participants which potentially control the release of the decision.

The first model, which is analysed briefly, is proposed by Pahl et al. (2007). It consists of a basic procedure which generically reduces DM to an undesirable initial state, a desirable goal state and obstacles that have to be overcome in order to reach the final, wanted state. While the first step (task) and the last step (solution) respectively represent the two above mentioned states, the block of obstacles is broken down into more detailed steps. Upon receiving a task, the decision maker will face the confrontation, then gather information, define the problem in order to set goals and define boundary conditions, create different possible solution alternatives and evaluate them to come to a decision which should finally be the solution to the problem. If the outcome of any step is unsatisfying, iteration cycles are intended where the decision maker can move back to any previous step to repeat it. These steps offer a good overview of the various steps of a DM process (Figure 1). However, it is modelled representing an isolated process and neglects the linkages to other participants.

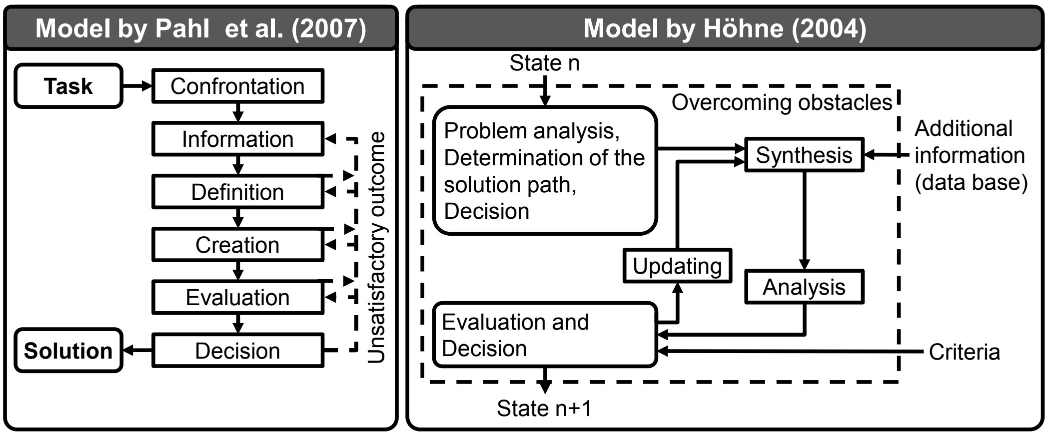

Figure 1. Model by Pahl et al. (2007) and model by Höhne (2004)

A model in which the input of outside criteria and information is considered is proposed by Höhne (2004). Apart from including these outside aspects, the “obstacle-block” is treated in a more generic way, leaving room for interpretation. According to Höhne (2004), a design decision process contains two basic types of decisions. The first decision determines the solution path and will be made after the given problem is analysed. The solution path is composed of the methods and tools that should be used as well as the compilation of a sequence in which the problem should be solved. Following the initial decision, the generic steps of information synthesis, analysis and evaluation will be executed according to the previously planned procedure. In the step “synthesizing”, the decision maker gathers all relevant information that are either available or have to be with-drawn from outside participants. Following the analysis of the synthesized information, the decision maker can choose to either continue to the next step or to repeat the synthesis in case that the obtained information is not sufficient. For the evaluation of the problem, criteria (e.g. from the requirements list) are taken into account. The methods and tools to execute the steps are only given generically, which leaves room for interpretation of the model. The decision following the evaluation is then either supposed to transform the previous, unwanted state n into the further concretised step n+1, or in case that no satisfying solution can be found an update is triggered that requires to repeat the procedure (see Figure 1).

Following the evaluation of the decision process, the potentially resulting consequences are focused upon. For this task, a model depicting the interrelations between a decision and its respective consequences has to be used. The model proposed by Hansen & Andreasen (2004) consists of two approaches (see Figure 2). The decision node represents the activities undergone during the DM process. This process is depicting the steps specifying, evaluation of alternatives, validation of design solutions, navigation through the design or solution space, unifying the decision into consisting wholes and finally deciding. This process is called evaluation and decision-making activity (EVAD). The decision map integrates EVAD into the relevant environment, which consists of the input of goals, alternatives, mind-sets and methods, the EVAD process and the product’s later activities. These activities can be purchase, production, distribution, use, maintenance and disposal. In addition to these activities, two other objects are designed during the PDP, which are the product itself and the life phase systems (e.g. production and distribution). On top of that, also the business of the company and the design process itself are designed, which leaves five dimensions that can potentially be affected by a decision made within the PDP. Consequently, this model can be used to identify relevant aspects that have an effect on consequences. It provides a good basis for evaluating these aspects as it depicts the interrelation of decision and consequence in a structured way. Considering that characterizing aspects were already compiled for decision situations, these characteristics should be evaluated regarding their adaptability for characterizing consequences as well.

The model by Hansen provides a rough explanation of how decisions are connected to resulting consequences. For a comprehensive analysis of the respective situations, an approach that puts a focus onto what is happening on behalf of the decision maker needs to be adapted. Schneeweiss (2003) proposes a model of DM on the basis of distributed decision making (DDM). Schneeweiss (2003) defines DDM as being the design and coordination of connected decisions (see Figure 2). When executing a decision, the decision maker will take into account the base-level’s characteristics, whereupon the base-level represents the consecutive and influenced decision. In the anticipation phase, the top-level decision maker uses the information he has from the base-level and formulates the characteristics of the base-level for himself (feed forward bottom-up influence or anticipation). The anticipation bases on certain criteria regarding the base level and, if taken into account by top-level, an expected reaction from the base-level. In a next step, the top-level influences the base-level by issuing an instruction. If the base-level is in the position to react to the instruction, it can in turn influence the top-level with its reaction (bottom-up influence). In this case, a further instruction-reaction cycle is triggered. When finally a decision is made and executed, the object system will be influenced which can again trigger feedback (ex post feedback). The distribution of top- and base level can, but do not have to be, linked to organizational hierarchical structures. Both levels do not even necessarily have to be different stakeholders (e.g. when the hierarchy of the system is represented by time). Thereby, a decision is made in some kind of uncertainty at the given point in time that shall be called t0 with respect to the given information at hand. Because of the fact that the decision maker does not know the exact state of information at a future point in time t1, he needs to anticipate that state of information using the information he has at the time t0 when the decision is made. For instance, when planning a product, the decision maker who needs to decide which design variant of a certain product to develop does not know which option will be liked more at t1 (e.g. when the product is on the market). Instead, he has to anticipate the choice of the customers by using the information he has at t0. The model by Schneeweiss (2003) analyses a decision in regard to how a decision maker observes the target object system with respect to anticipating its reaction to the decision. Apart from embedding the model into the overall decision analyzing method, no major action will be needed for this model.

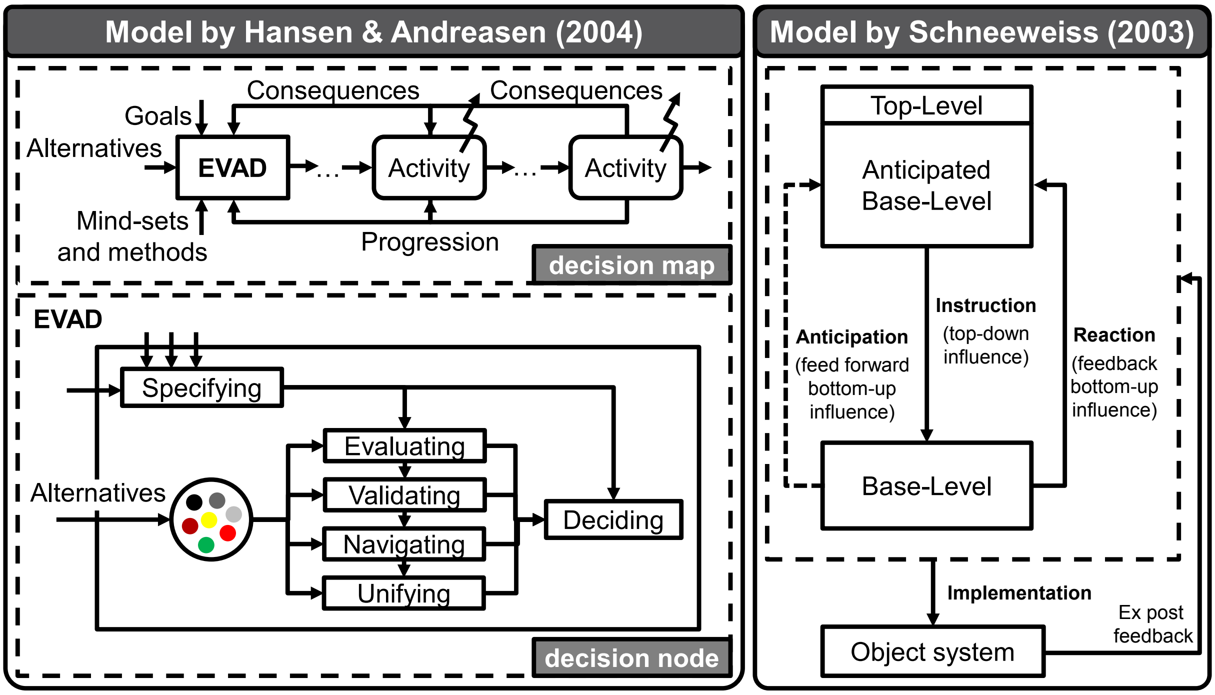

Figure 2. Model by Hansen & Andreasen (2004) and model by Schneeweiss (2003)

3 METHODOLOGY TO MODEL AND MAP INTERCONNECTED DECISION MAKING SITUATIONS AND THEIR CONSEQUENCES

The models presented and evaluated in section 2 will be merged, partly modified and complemented to create a methodology that is able to depict the linkages between DM situations and their characterizations and consequences. The overall methodical procedure (see Figure 3) consists of four main phases: mapping DM situations onto a PDP (Section 3.1), characterization method for DM situations (Section 3.2), modelling DM situations (Section 3.3) and evaluation of consequences (Section 3.4).

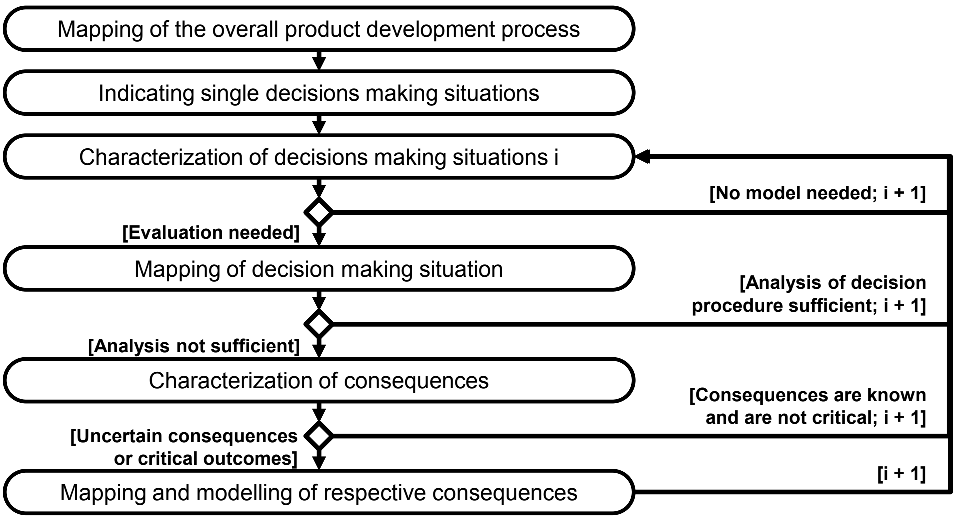

Figure 3. Overall methodical procedure (modelled with UML)

3.1 Mapping decision making situations onto a development process

As a PDP consists of many interrelated decisions, the previously elaborated models will be embedded into a logical system of decisions regarding functional backgrounds. Therefore, the model which is proposed by Ottosson and supplemented by Vajna & Burchardt is combined with the process by Chen et al.. The model provided by Chen et al. offers the opportunity to merge the perspectives that are part of a PDP into one model. The previously stated model by Ottoson gives an estimation of how the relative involvement of different functional departments (respectively perspectives) is distributed throughout a PDP. Based on this model, Vajna & Burchardt (1998) indicate decision situations with ovals.

This distributed, inter-functional DM based engineering design model, which is combined from the three mentioned models, allows mapping cross functional relations between decisions in a logical way. With help of the model by Chen et al., the distribution of these decisions indicating ovals can be backed up with a logical system that explains the derivation of the stated distribution of decisions. Hence, the entities stated by Chen et al. are linked to the different functions or functional perspectives that occur in the model presented by Ottosson. This allows the distribution of entities throughout the functional distribution model by Ottosson which fulfils the function of a guiding map in a generic way. Depending on how the specific company or project is organized, these perspectives are expressed using the respective functional departments. A generic example of this model is shown in Figure 4.

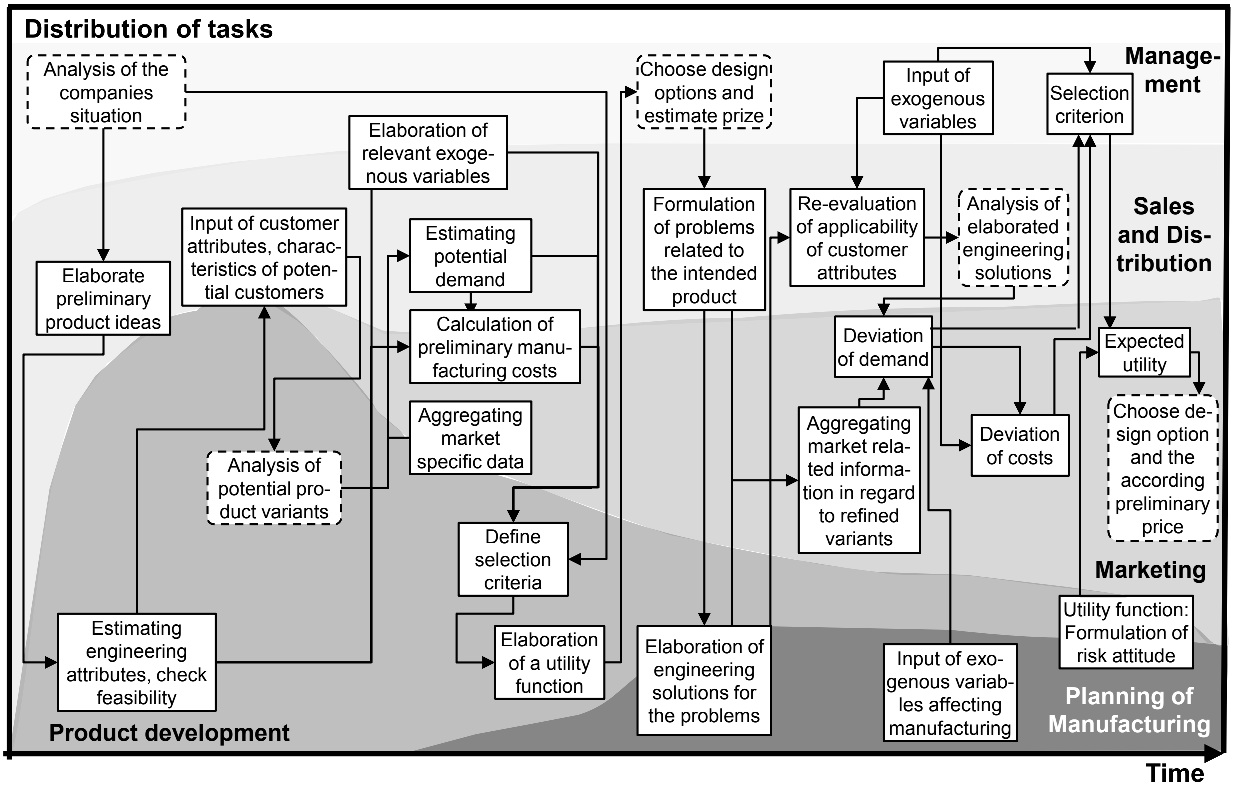

Figure 4. Distributed, inter-functional decision making based engineering design

3.2 Characterization method for decision making situations

Grünig uses the term "dimension" to describe which aspect of a decision is regarded and defines assigned characteristics. According to that pattern, one example for a dimension would be the difficulty of a decision. Its assigned characteristics are "simple" and "complex". In contrast, Orasanu et al. define eight characteristics. Each of these characteristics increases the difficulty of DM for the regarded decision. While to a large extend both authors provide complementing characterizing aspects and, therefore, both will be used. Consequently, overlapping dimensions have to be synchronized. In the following Figure 5, the dimensions that are used to characterize DM situations are listed with their possible characteristics. The dimensions whose characteristics are divided by a diagonal line can be expressed in no further defined increments. Due to the fact that Orasanu et al., in contrast to Grünig,

only use characteristics instead of dimensions, these characteristics are indicated with underscores while the missing characteristics as well as the dimensions are logically added.
As the characterizing dimensions of decision situations are intended to build the basis for analysing a decision, each dimension has to be rated in regard to how much the respective dimension reveals about the need to evaluate a decision situation in more detail. The assignment of weights to each dimension can be done either globally or case specific. The relative importance of the characterized dimensions is used to decide which situations have to be further analysed. Since this methodical procedure cannot be completely concrete, room for flexible interpretation is given. While the characterization will serve as a way to estimate decisions in regard to their potential to induce unwanted consequences, it can serve various further needs for future works. When evaluating decision support methods, the characterization could be used in order to assign support methods to certain characterizing patterns.

Dimension	Characteristics		
(1) Degree of difficulty	Simple	Complex	
(2) Problem structure	Well-structured	Ill-structured	
(3) Composition of the solution space	Choice problem	Design problem	
(4) Motivation to act	Chance	Thread	
(5) Dependency on other decisions	Independent	Dependent (Part of a decision sequence)	
(6) Layer of the problem	Original problem	Meta problem	
(7) Type of actor	Single perspective	Multiple perspective	
(8) Number of pursued goals	Low number	High number	
(9) Predictability of outcomes	Definitely predict-table outcome	Multiple con-sequences possible with predictable probability of occurrence	Multiple con-sequences possible without pre-dictable pro-bability of occurrence
(10) Environmental dynamics	Stable environment	Changing environment	
(11) Quality of the definition of the target goal	Defined, stable or clear goal	Shifting, ill-de-fined or competing goal	
(12) Time stress	Low	High	
(13) Organizational norms and goals	Available	Not available	

Figure 5. Decision making dimensions with corresponding characteristics

3.3 Modelling decision making situations

Based on the above described model by Höhne, a model is introduced in this section which enables to depict decision situations in a structured and reproducible way. Following the evaluation in section 2.3, certain aspects have to be included into this model (see Figure 6).

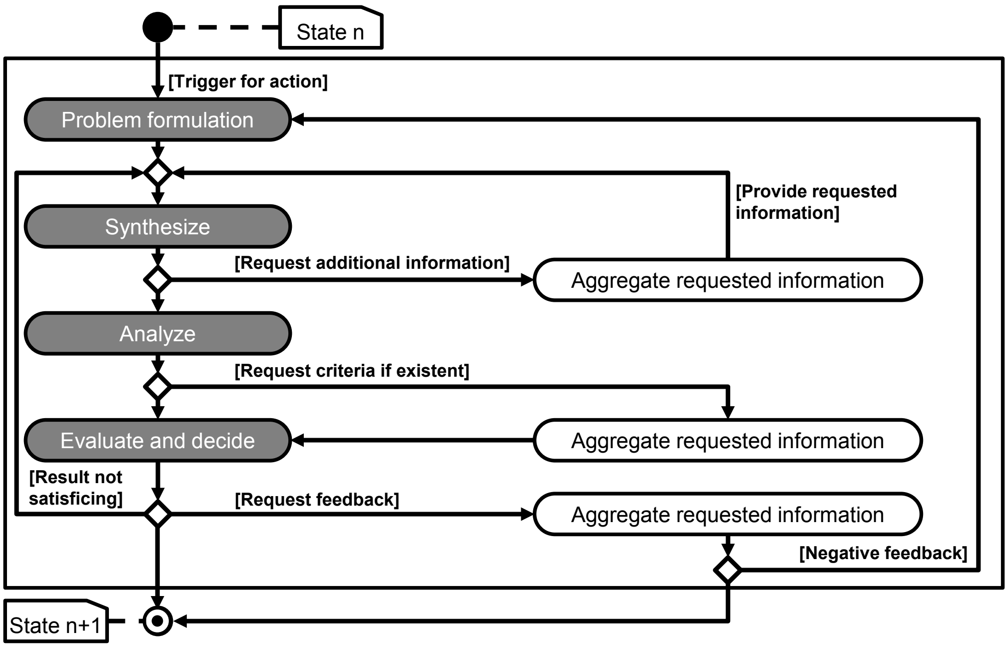

Figure 6. Decision making process (based on HÖHNE; modelled with UML)

To start with, a trigger for action is supposed to be added. Furthermore, iteration steps should also be implemented in order to leave the possibility to repeat certain steps in case of unsatisfying results. While the model by Höhne already includes the input of information and criteria, the framework will be expanded by the need to actively request these information and criteria. The request for additional information is made after available information is synthesized and a lack of information is detected. Additional information leads to repeating the synthesis. Upon the analysis, restricting criteria can be requested and taken into consideration for the final evaluation and decision. The procedure of additional input at the time when the certain steps are undergone can work as a shortcut, as negative feedback can be avoided and the decision is more likely to be implemented without further iteration cycles. The actions that are executed by the decision maker at a certain situation are presented in Figure 6 in dark colour. For the other actions that are indicated, other participants or data systems are involved.

3.4 Evaluation of consequences

Serving the further procedure, consequences will be divided into two categories. The first category of consequences occurs before the start of production (SOP) and during the PDP. The second category occurs post SOP, affecting above for all participants outside of the company. While a direct feedback request directed to participants within the own company is comparatively easy, obtaining feedback from outside participants (e.g. customers) will require another procedure.

The characterization of decision situations already provides information about the dynamic development of the environment, a characteristic that should also be considered for consequences, due to the fact that consequences generally occur with time delay and are therefore potentially affected by environmental dynamics. Apart from that, further characteristics have to be considered when evaluating consequences. Due to a lack of literature on this issue, a compilation of characteristics is elaborated.

First, a simple process that indicates the interrelation between a decision and consequences is used to depict relevant characteristics. This process is based on an approach provided by Hansen & Andreasen and has been adapted significantly (Figure 7). It indicates the time delayed impact of a decision and its potentially resulting feedback to the original decision maker. Characteristics regarding the consequences of a decision are derived from the different stated aspects that are shown in Figure 8.

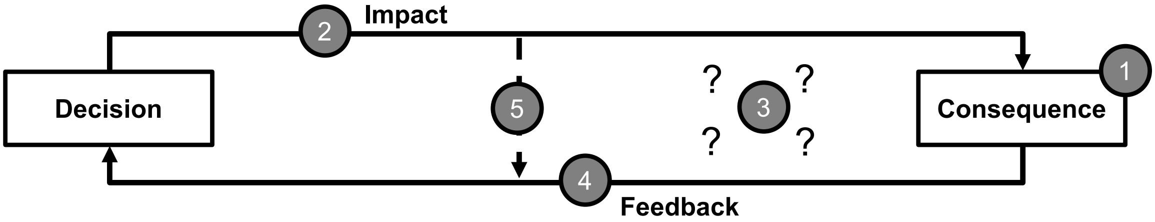

Figure 7. Modelling consequences of decisions

From the decision makers point of view, knowledge about and intention to trigger the consequence have to be regarded (1). Intended consequences are considered to always be known consequences. Unintended consequences can be known or unknown. Apart from characterizing the consequence itself, further characteristics can be derived and are summed up in Figure 8. Another characteristic is the time wise delay with a consequence occurs after a decision is made (2). This has an impact onto the possibility of a decision maker to react to that consequence and onto the potential degree of environmental changes (3). These environmental changes, indicated with question marks, can change the conditions for consequences. For instance, due to changing environmental conditions, a previously intended consequence can turn out unfavorable. A further characteristic that has to be reviewed is the feedback the decision maker gets after a consequence has occurred or is detected (4). Feedback can lead the decision maker to correct future decisions and provide the potential to influence unwanted outcomes retrospectively. A fifth indicator is a shortcut, which leads to confront the decision maker with a potentially occurring consequence before it is happening (5). This shortcut is especially favorable in case of unfavorable consequences that were previously unknown. The shortcut is introduced to emphasize the need to share information about a decision with potentially affected decision makers. In case that a potentially affected participant detects an unfavorable consequence, the stated shortcut can be shifted into the decision process, leading to a correction of the decision (almost) without time delay.

Dimension	Characteristics		
1 **Perception of consequence**	Intended These consequences will either be the target of the decision or some welcome side-effects.	Unintended-known These consequences will be side-effects that should be considered.	Unintended-unknown Consequences that are considered important to reveal and avoid if possible.
2 **Time to impact of consequence**	Short		Long
3 **Environmental dynamics**	Low		High
4 **Feedback to decision maker**	Immediate		Delayed
5 **Detection of consequence before impact**	Possible	Not possible	

Figure 8. Characterization of consequences

4 CONCLUSION AND OUTLOOK

This contribution aimed to determine a methodology to model and map DM situations within product development with regard to their respective consequences. In order to reach this goal, existing models and methods regarding DM in product development were evaluated and revised. Additionally, characteristics of crucial situations and consequences were analyzed to provide a consistent evaluation approach. Following the evaluation of the respective situations, critical situations were picked out and modelled with the help of a DM procedure, depicting the logical cognitive steps as well as integrating outside participants into the process. Future research work will deal with the application of the overall methodology in a fictive as well as in an empirical industrial case study and the improvement of the methodology due to the lessons learned. Thereby, the decision making and operations research literature has to be considered in detail. This should allow to improve and to validate the proposed models.

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