ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

DEPLOYING DECISION CRITERIA IN A CYCLICAL DECISION PROCESS FOR THE PRODUCT PLANNING PHASE

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ABSTRACT

During the planning process of future products or the future product portfolio, ideas for future market opportunities are generated and within a parallel decision process, the best ones are selected. This paper presents a method for the decision process during that product planning process. The focus is on the selection and weighting of the decision criteria. The method is applicable for planning processes with reoccurring decision steps. Therefore a block model is introduced: in every decision step a new block, compromising a set of criteria is added to the existing blocks and thus more and more integrated decisions can be made about the planning alternatives. Based on that the criteria are weighted consecutively in order to assure consistency between the different decision steps. Therefore we show rules for deriving the weighting factors of decision criteria in that additive decision process.

Keywords: decision criteria, decision making, product planning

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1 INTRODUCTION

The planning of the product portfolio sets the course for the future success of a company. Within this process, the products to be developed in the future are more or less defined (Pahl et al., 2007, Ulrich and Eppinger, 2011). The planning process of products has been discussed amongst others by Pahl et al. (2007), Agouridas et al. (2008), Ulrich and Eppinger (2011) and Hepperle (2013).

During that process, several decisions have to be taken about the products and the product portfolio on different levels of product concretization. In these decisions, solutions are selected under consideration of competing and conflicting goals regarding cost, quality and time. Decisions are made about future products and technologies as well as their scheduling (Hepperle, 2013). Several stakeholders with different knowledge, responsibilities and views are involved (cp. Falessi, et al. 2011). An overview of the influencing dimensions on decision processes in product development is given by Jupp et al. (2009).

The goal of decisions within product planning is the selection of the best choice within a set of alternatives. Decisions are an active instrument within the innovation process for assuring the highest possible innovation success. Ahead of the actual decision, there is an evaluation in which the actual properties of the decision alternatives are compared to reference properties. The reference values are brought into the process by defining the decision criteria. Actual properties are gained by measuring or estimation (Falessi, et al., 2011).

Decision making has been widely discussed in the literature. (Falessi et al., 2011), Pohlmeyer (2001), Grünig and Kühn (2005), Pahl et al. (2007) and Gigerenzer and Gaissmaier (2011) discuss decision making and decision methods that differ in their scope as well as their field of application. Methods for decision making have been established in various disciplines such as engineering, computer science, management science or psychology. Selecting one alternative out of a finite set of alternatives is the typical selection problem in engineering that is supported by using multi-attribute decision making techniques (Fallessi et al., 2011).

Methods for decision making are applied in order to improve the handling of the complexity regarding the multitude of product properties as well as influencing factors that have to be accounted for (Pahl et al., 2007).

There is a decision process with consecutive decision steps in parallel to the planning process. The iterations of the process follow a similar pattern (cp. Eide et al, 2002).

We propose an approach for an integrated decision process with a consecutive weighted set of decision criteria. With each decision step, the decision criteria are completed and concretized in order to take into account the rising level of concretization of the decision object.

The arising research questions for this paper are:

- Which decision criteria may be applied in each decision point of a decision process in parallel to the planning process and how can their relative importance be determined?
- How can the interdependencies of cyclical decisions be modelled in a decision model?

In the following we propose a classification for decision criteria for the product planning phase as well as a method for cyclical decision processes focussing on deployment and weighting of decision criteria in order to apply known decision methods for multi-stepped-decision processes. In section 4 we show its application in a case study.

2 DECISION CRITERIA

Core elements of every decision method are decision criteria. In accordance with the definition of product properties given by Birkhofer (1980), a decision criterion consists of a characteristic and its specification. Characteristics describe the evaluated characteristic of the decision object, such as the weight, engine performance or capital value. The specification quantifies or qualifies the characteristic. In the decision process, the actual value of each characteristic alternative is compared with a target value. Thus the decision criteria are used for the evaluation of a decision object (thus the term "evaluation criteria" can be used synonymously). The target value may be qualitative or quantitative. Quantitative target values may be represented by a value function. Value functions assign technical or financial characteristics to scores. For example, the manufacturing costs per item (in a value range between 100 and 120 €) are assigned to a score (between 0 and 1). Thereby increasing or decreasing linear or exponential functions can be applied (cp. (Pahl et al., 2007), (Roozenburg and Eekels, 1995)).

Decision criteria model those properties of a decision object which are accounted for within a decision. Thus, the chosen decision criteria have a crucial impact on the outcome of a decision process. Within the decision process, only those properties which are modelled as decision criteria are considered. Properties that are not represented within the set of the decision criteria are disregarded. The application of wrong decision criteria leads to a lower decision quality (Dünser and Meier, 2004).
Decision criteria have to be unique and consistent (cp. Breiing and Knosala, 1997). Figure 1 gives an overview of relevant classes of decision criteria considered within the planning process. These classes have been taken from Breiing and Knosala (1997), Cooper and Edgett (2002), Zeithaml et al. (1990) and Kaplan and Norton (1992). Decision criteria can be distinguished in two main categories: internal and external ones. Whereas the internal ones account for the goals of the company that plans the product and account for the products, the product portfolio as a whole, financial aspects and a coherence with the strategy, the external ones account for the customer, suppliers and context factors. These have been discussed in detail by Langer and Lindemann (2009).

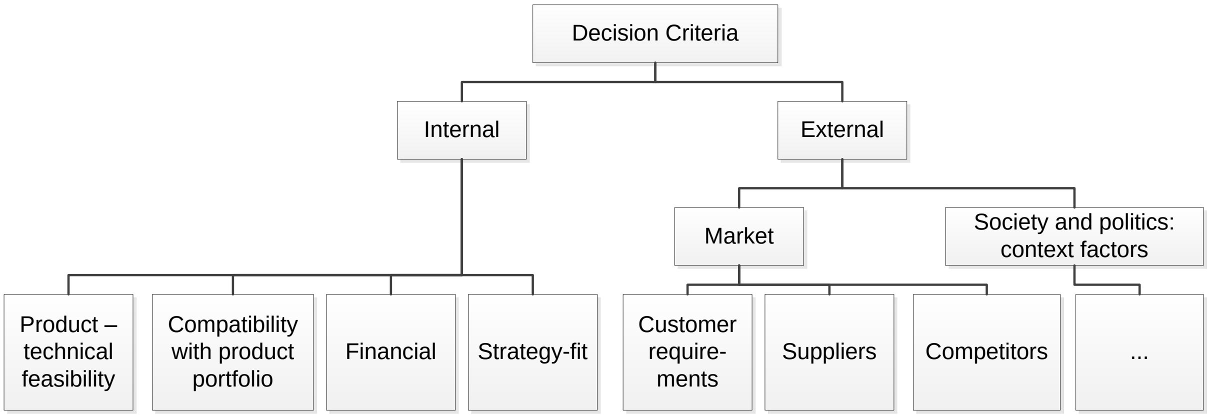

Figure 1. Decision criteria

As written above, decision criteria are those properties of the object of a decision which are accounted for within a decision. In the context of decisions within planning processes, decisions are taken about product alternatives that should fulfil the requirements regarding the priority of the requirements. Decision criteria may be deduced from a requirements list (Breiing and Knosala, 1997). In the early phases, when no requirements list yet exists,, the set of decision criteria forestalls the latter requirements list. However, decision criteria and requirements may differentiate within their level of abstraction or properties of the products which are modelled.
Within the decision process, the decision criteria are weighted by assigning a weighting factor in order to increase or decrease their influence on the overall result. "A weighting factor is a real, positive number. It indicates the relative importance of a particular evaluation criterion (objective)" (Pahl et al., 2007). For valid results in a decision method, the range of the value function of a decision criterion has to be considered (cp. Eisenführ et al. (2010)). It has to be kept in mind that a completely objective weighting is not possible in practice: "In all evaluation methods using weighted criteria […], the importance is deducted from subjective estimations of participating experts. Despite all methodological supports to objectify the importance, in highly complex situations, where it is not possible for a human being to overview all relevant aspects, the quality of such estimations can be very low" (Dünser and Meier, 2004). The importance can be expressed in four ways: no articulation, direct weight, elicited weight and utility curve (Falessi et al., 2011).
A wide range of different methods is known from literature for the weighting of decision criteria. Examples therefore are the pairwise comparison (Breiing and Knosala, 1997), the Analytic Hierarchy Process (AHP), which is based on the decomposition of a decision problem into a criteria hierarchy (cp. Saaty, 2000) or the Kano Model, which focusses on customer needs (Bayus, 2008).

3 CYCLICAL DEPLOYMENT AND WEIGHTING OF DECISION CRITERIA

In this section we describe the approach for the deployment of criteria and introduce the so-called block model. The weighting of criteria within this block model is discussed. Possible cases for deriving the weighting factors of decision criteria in this additive decision process are discussed and calculation rules are given.

3.1 Deployment of criteria: Block model

For the deployment of decision criteria within the decision process a model representation is used that is described in the following (cp. figure 2). The model representation of the decision process is a sequence of several consecutive decision steps (figure 2: decision steps I-IV). The applied decision criteria are taken from the wholeness of possible decision criteria. The criteria can be taken from a checklist or a database. On higher levels of abstraction, these can be given universally applicable (as given in figure 1). The specified criteria are product-specific.

Within one step of the decision process, a set of criteria from these possible criteria is taken. One set of criteria is represented by one block in figure 2. The selection process of these criteria is additive. For each step a new set of criteria (block) is added to the existing blocks. In decision step I, a set of criteria is taken and put into block I, in decision step II, additional criteria are taken and put into block II and are considered in addition to block I and so on. By using that approach, the applied criteria for each decision are specified successively.

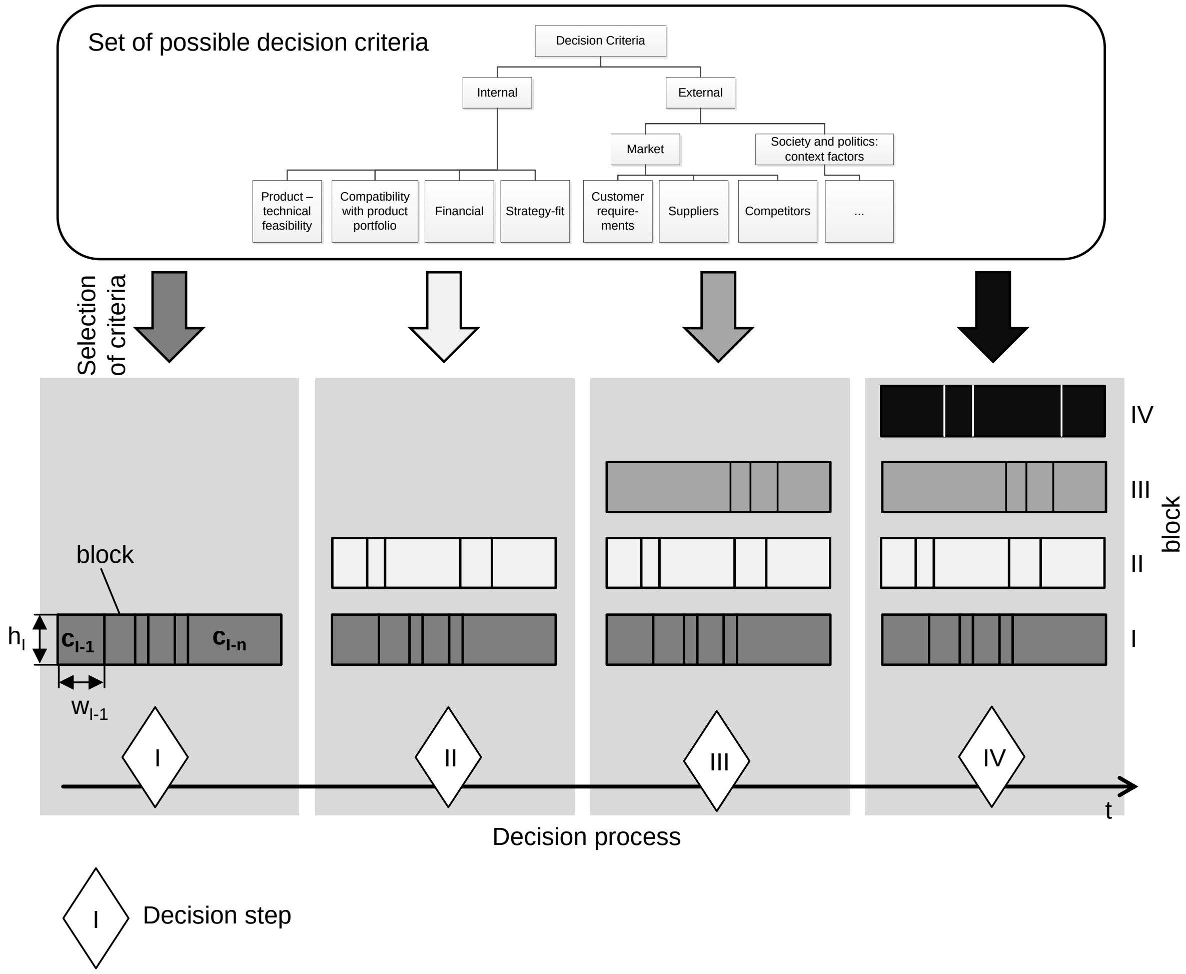

Figure 2. Model representation: decision criteria within the decision process

The criteria within one block are weighted in relation to each other. The blocks (and thereby the entity of criteria within one block) are weighted in relation to the other blocks. There are two multiplicative weighting factors for each criterion: one factor for the weighting of one criterion within a block and one factor for the weighing of the whole block. Furthermore, there is the possibility of the specification of decision criteria. In this case a superior criterion is split into two or more criteria within the same block. That complies with the demand that decision criteria must be unique and consistent (cp. section 2).

The possibility of addition and specification is an additional support for the decision-maker because it is not necessary to have all criteria at the beginning. They can be specified and completed successively in the different steps. The decision criteria for the previous steps are considered in every decision step in order to have an integrated evaluation of the product properties. The next section gives an approach for establishing weighting factors that take into account this cyclic decision process. Cyclic decision process means thereby that there are reoccurring decisions on a more and more concrete planning object with a consecutive set of decision criteria.

3.2 Weighting of criteria

After selecting the criteria, the goal is now to weigh them up in relation to each other. The reason for this is that the criteria differ in their importance. The weighting of the criteria is of high significance within the decision process since it has a crucial impact on the outcome of a decision method. For example, the ranking of decision alternatives within the planning process of a radical innovation depends significantly on the emphasis of risk in customer acceptance and technical feasibility. A low weighting of these criteria will result in a different ranking to a decision accounting mainly for these criteria.

The procedure for the weighting of the criteria is shown in figure 3. One block contains the criteria c_{b-1} to c_{b-n}, (with b being the consecutive number of the block or decision step and n being the consecutive number of the criterion within one block) in the set of criteria. In figure 3, the length of one rectangle of one criterion represents the weight of the criterion w_{b-n} in this block and the height of one block represents its weight h_{b-n} in relation to the other blocks.

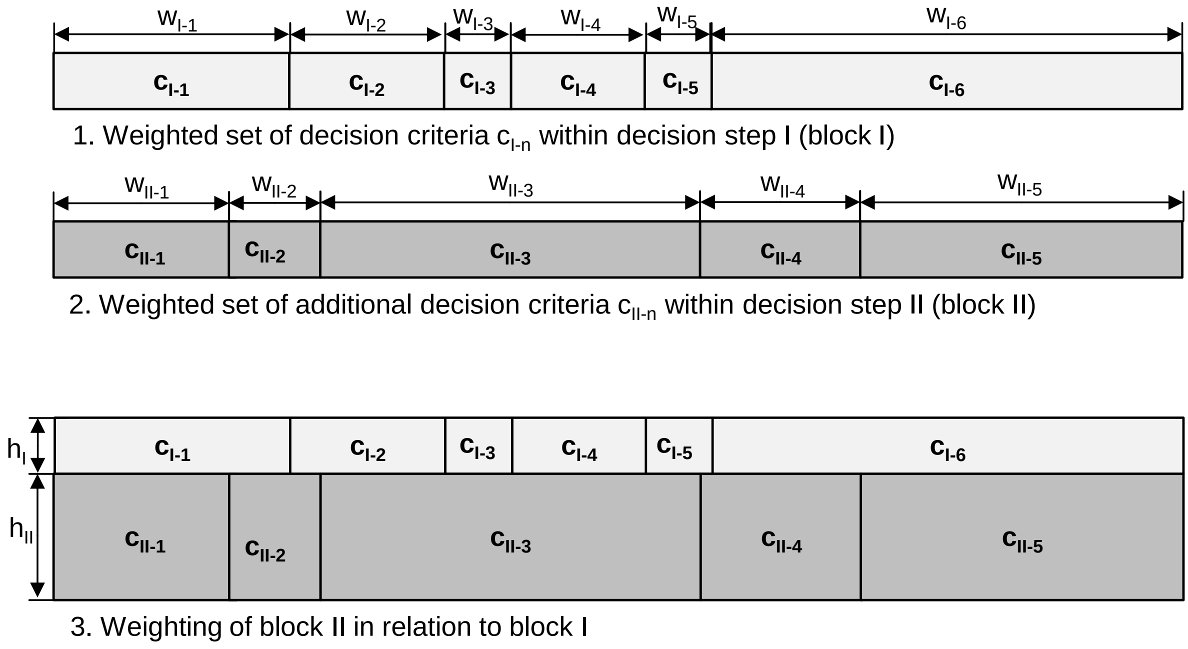

Figure 3. Weighting of criteria

In the first decision step of the process, the criteria within one block are weighted in relation to each other, scaled to 100 % (1.). In the next decision step a second block, comprising a new set of criteria, is added. The new criteria within the second block are also weighted in relation to each other (2.).

After weighting the criteria inside the blocks, the focus is now on weighting the blocks in relation to each other, in order to get an overall weight (represented by the height of one block in figures 2 and 3) of all criteria (3.). That can be achieved by a cumulative comparison of the importance of blocks or the usage of a reference weighting factor from the first block that is compared to the weighting factors within the second block. The added heights of the block are 100 %. The overall weighting factor A_{b-n} of one criterion (for use e. g. in a utility analysis) is calculated as follows:

$$A_{b-n} = w_{b-n} h_b \tag{1}$$

The approach for selecting and weighting the criteria for a multi-stepped decision process is introduced above. In the following we discuss the different cases for the evolvement of the set of criteria in a new block and give calculation rules. There are three cases for one criterion: new independent criteria, the specification of criteria and a modification of its specification.

Case 1: new independent criterion
New criteria are added in a decision step for considering additional aspects within a decision. In this case the criterion is added to the new block as shown in section 3.1.

Case 2: specification of criterion
In the case of a specification of one criterion the original criterion is split into two or more new criteria within its original block. The weight of the original criterion is distributed across the new specified criteria, following the condition given below:

$$w_{b-n} = \sum_m w_{b-n,m} \quad (2)$$

w_{b-n}: weighting factor of criterion n in block b
$w_{b-n,m}$: weighting factor of criterion m, being a specification of criterion n, in block b
For example, the criterion c_{I-3} = cost is detailed into c_{I-31} = manufacturing cost and c_{I-32} = development cost. The weighting factor w_{I-3} = 0.3 is divided into a weighting factor w_{I-31} = 0.2 for the criterion c_{I-31} = manufacturing costs and the weight factor w_{I-32} = 0.1.
Weightings of decision criteria risk producing the splitting effect: very detailed (split) criteria tend to receive a higher weighting in sum compared to their superior (aggregated) criterion (Eisenführ et al., 2010). This effect may be overridden by distributing the weighting factor across its subordinate criteria.

Case 3: modification of its specification
Since the criteria are getting more specific as the level of concretization of the planning object rises in the ongoing planning process, a modification of the specification of a decision criterion usually means narrowing the range of the value function. The motivation for a specification is the need for a more precise significance of a specific aspect within a decision.
In this case also, the weight of the criterion has to be modified. The approach is that the range of the value function (being the specification of the decision criterion) is shortened. As shown by Eisenführ et al. (2010), the weighting factor must be considered for the attribute range. Thus the weighting factor has to be adapted as described below. The idea is that the weighting of the modified criterion is reduced proportionally to the narrowed value function and the weighting factors of all criteria and blocks are adapted in order to maintain a cumulative weighting of 100 %. Due to this condition, a modification of the specification of a criterion does not change the resulting ranking of the decision alternatives that are inside the value function. That is consistent with the requirement on weights that the weight of a criterion with a more narrow range of the value function has to be smaller than for a broader range in order to maintain the value differences between the different attribute levels of the decision alternatives (Eisenführ et al., 2010).
First, a correction factor f_c is calculated as follows:

$$f_c = 1 - \frac{r_{b-n} - r_{b-n'}}{r_{b-n}} w_{b-n} \quad (3)$$

r_{b-n}: range of value function of criterion c_n within block b
r'_{b-n}: narrowed range for criterion c_{b-n}
This correction factor is used for calculating the modified weighting factor w_{b-n}' for criterion c_{b-n}:

$$w'_{b-n} = \frac{r_{b-n'}}{r_{b-n}} \frac{1}{f_c} w_{b-n} \quad (4)$$

w_{b-n}: original weighting factor for criterion c_{b-n}
The weighting factors for the criteria c_{b-i} within block b are adapted in order to maintain their relative weights to w'_{b-n}:

$$w'_{b-i} = \frac{1}{f_c} w_{b-i} \quad (5)$$

The sum of all weighting factors within block b is 100 %. The weight of block h_b has to be adapted in order to maintain the overall weight of a single criterion:

$$h'_b = \frac{f_c h_b}{1-(1-f_c)h_b} \quad (6)$$

In the next step the weighting factors h_m of the other blocks have to be adapted as follows. The sum of all weighting factors of the blocks is 100 %:

$$h'_m = \frac{h_m}{1-(1-f_c)h_b} \quad (7)$$

This approach is realized in a short example: The value range of the value function of the criterion $c_{I\text{-}3}$ = manufacturing cost per item is between 100 and 130 €. It is specified on 100 to 120 €. Its weighting factor is $w_{I\text{-}3} = 0.3$. The weighting factor of the block is $h_I = 0.6$. So the range $r_{I\text{-}3} = 30$ € and the modified range $r'_{I\text{-}3} = 20$ €. By application of (2), the correction factor is calculated as $f_c = 0.9$. The modified weighting factor is $w'_{I\text{-}3} = 0.222$. By application of (4), the sum of the other weighting factors is 0.778. The weight of the block is $h'_I = 0.574$.

For the case of a broader range of value function, an applicable formula can be found in Eisenführ et al. (2010). A shifting of the value function with a constant absolute range has no impact on the weighting. Based on that, every modification of the specification can be calculated by a sequential combination of narrowing/broadening and shifting.

4 CASE STUDY

The presented approach has been applied to the data of decisions of a student project. The goal of the case study was to evaluate the applicability of the approach in principle.

In that student project, a team consisting of nine students from mechanical engineering and computer science developed a concept for a bicycle sharing system. Their planning task was to develop the whole concept including bikes as well as infrastructure. The system was intended to provide its customers with short-term rental bikes in a floating system. This means that the bikes have no fixed base. They can be left at any appropriate place within the renting area (e. g. a city centre) and can be picked up there by the next customer. The available bikes may be located and booked by a smartphone app. The initial point was a commercial e-bike. Within the planning phase of the project, decisions have been made about several concepts for the infrastructure (backbone), the on-board-computer of the e-bikes, functions to be realized in the infrastructure and e-bikes (e. g. navigation system, damage notifications) as well as modifications of the bike (e. g. integration of battery charger). The student team was instructed to document every decision including decision object and applied decision criteria. Selection of decision criteria and the decision making were done in the interdisciplinary team. The decision criteria represent the requirements of the different domains within the team and have been selected in team discussions.

The result of the application of the method is shown exemplarily below on the collected data of the student project for two decision steps. The decision objects were concepts for the e-bike (decision step I) and the on-board-computer (decision step II).

The method was implemented in an Excel template. Figure 4 shows the decision criteria and their weighting factors for decision step I. The weighting factors have been deployed by using a pairwise comparison.

	Decision criterion	Weighting factor criterion $w_{I\text{-}n}$
Block I	$c_{I\text{-}1}$ Safety	23.0%
	$c_{I\text{-}2}$ Performance	20.0%
	$c_{I\text{-}3}$ Technical feasibility	35.0%
	$c_{I\text{-}4}$ Operating distance	16.0%
	$c_{I\text{-}5}$ Robustness	6.0%

Figure 4. Decision criteria for decision step I

Figures 5 and 6 show the decision criteria and their weighting factors for decision step II. The criterion $c_{I\text{-}1}$ safety was split into the two more specific criteria $c_{I\text{-}1,1}$ access control and $c_{I\text{-}1,2}$ operation reliability. The criterion $c_{I\text{-}3}$ technical feasibility was applied unchanged in the decision step. The criteria $c_{I\text{-}2}$ performance and $c_{I\text{-}4}$ operating distance were applied additionally in this step by the application of the proposed method. In the original data these criteria were not applied in decision step II. The criterion

c_{I-5} robustness was split into the two more specific criteria $c_{I-5,1}$ operating conditions: temperature and $c_{I-5,2}$ operating conditions: rain. Blocks I and II were weighted with the ratio 70:30 by estimating their cumulated importance.

	Decision criterion	Weighting factor criterion w_{b-n}	Weighting factor block h_i	Overall weight A_{b-n}
Block I	$c_{I-1,1}$ Access control	14.0%	70.0%	9.8%
	$c_{I-1,2}$ Operation reliability	9.0%		6.3%
	c_{I-2} Performance	20.0%		14.0%
	c_{I-3} Technical feasibility	35.0%		24.5%
	c_{I-4} Operating distance	16.0%		11.2%
	$c_{I-5,1}$ Operating conditions: temperature	3.6%		2.5%
	$c_{I-5,2}$ Operating conditions: rain	2.4%		1.7%
Block II	c_{II-1} Multiple use	17.0%	30.0%	5.1%
	c_{II-2} Efforts for installation	34.0%		10.2%
	c_{II-3} Quality	23.0%		6.9%
	c_{II-4} Usability	26.0%		7.8%

Figure 5. Decision criteria for decision step II

In decision step I the range of the value function of c_{I-4} operating distance was 25-75 km. Due to the results of a customer survey, that range was narrowed to 50-75 km. Thus the weighting factors had to be adapted as given in section 3.2, case 3. The results are shown in figure 6. The rounded overall weights are the same as in figure 5 without the modification. A specification to a more narrow range would lead to a slightly different distribution of the weighting factors. However, in this use case, the possible influence of the correction factor is negligible.

	Decision criterion	Correction factor f_c	Weighting factor criterion w'_{b-n}	Weighting factor block h'_b	Overall weight A_{b-n}
Block I	$c_{I-1,1}$ Access control	-	14.8%	68.8%	10.2%
	$c_{I-1,2}$ Operation reliability	-	9.5%		6.6%
	c_{I-2} Performance	-	21.2%		14.6%
	c_{I-3} Technical feasibility	-	37.1%		25.5%
	c_{I-4} Operating distance	0.94	16.9%		11.7%
	$c_{I-5,1}$ Operating conditions: temperature	-	3.8%		2.6%
	$c_{I-5,2}$ Operating conditions: rain	-	2.5%		1.7%
Block II	c_{II-1} Multiple use	-	w_{II-1}	31.2%	5.3%
	c_{II-2} Efforts for installation	-	w_{II-2}		10.6%
	c_{II-3} Quality	-	w_{II-3}		7.2%
	c_{II-4} Usability	-	w_{II-4}		8.1%

Figure 6. Decision criteria for decision step II

5 CONCLUSIONS

The applicability of the proposed approach as well as its advances and limitations are discussed in this section. The method focuses on multi-stepped decision processes. It uses a consecutive set of decision criteria that is enhanced within every decision step of the decision process.

The contribution of this paper is a concept for a cyclic decision process that crosslinks the applied decision criteria of each step including their weighting. For the selection and weighting of criteria and the ranking and evaluation of the alternatives common methods such as the pairwise comparison and the utility analysis can be applied. The method uses a hierarchical set of criteria, similar to the Analytic Hierarchy Process (AHP). Beyond that, the method allows for (and demands) an extension of the set of criteria in every decision step.

The method has been used in a case study of the data of a student project. The main challenge was the weighting of the blocks against each other. Two possible ways to deal with this can be suggested: The most pragmatic way is to estimate the importance of the cumulated criteria within one block. Alternatively, a subset of the already weighted blocks is integrated into the criteria weighting of the new block. The weighting of the blocks can be calculated from this.

The application of the method in a use case showed that the amount of data is quite complex. The set of decision criteria increases with every decision step. Therefore the method must be applied within a computer-based tool in order to minimize the required effort and to facilitate applicability in industry. In the case study this was done prototypically with an Excel template.

In industrial practice (as well as in the observed student project of the case study) many decisions are made or at least prepared by teams. Due to the decomposition of the decision problem to several persons, the cognitive load for each individual is reduced. The different views of the team members are represented by the different decision criteria. The consecutive decision process also accounts for the views of the previous decision steps.

Breiing and Knosala (1997) demand an attentive documentation of the applied decision criteria for every step of a multi-stepped decision process. In the proposed method this is done by putting the criteria in blocks that are assigned to decision steps.

In the proposed method, criteria are not removed from the set of decision criteria. The underlying assumption is that properties of the decision that were relevant in one decision step are still relevant for the later decisions in order to gain an integrated evaluation of the decision alternatives. The properties of the decision alternatives may be taken from the earlier decision steps if there are no changes, so the additional effort for carrying the criteria from the earlier steps is negligible (or non-existent if the method is implemented in a computer tool). However, changes of properties of the decision alternatives or the goals must be considered. Reasons for changes result from uncertainty, ambiguity and fuzziness in the planning of relevant information. Due to the integrated evaluation approach, this method is preferably applied for decisions on the system level or at least main components. Using the proposed method for decisions on subordinated components (with decision criteria taking into account all relevant properties of the system) would be like cracking a nut with a sledgehammer.

One issue is the availability of information about the decision alternatives within the planning phase. An appropriate selection of the decision criteria may show which pieces of information have to be available for a decision. Only those decision criteria which are relevant should be applied. Considering irrelevant decision criteria may cause time to be wasted in obtaining that information. Due to a higher number of decision criteria, the complexity of the decision method is increasing and thus the outcome is becoming less transparent. Not every piece of required information will be available during decision processes in product planning. In this case, estimations have to be made or different decision criteria have to be chosen. Closely related to that is the quality of information resulting from the uncertainty and ambiguity of information in the planning phase. The information quality has to be kept in mind during the decision process. Appropriate approaches for handling uncertain und ambiguous information about (amongst others) product properties, customer demands, future changes of corporate strategies have to be applied.

ACKNOWLEDGMENTS

We thank the German Research Foundation (Deutsche Forschungsgemeinschaft – DFG) for funding this project as part of the collaborative research centre ‘Sonderforschungsbereich 768 – Managing cycles in innovation process – Integrated development of product-service-systems based on technical products’. Furthermore we would like to acknowledge the support of Lukas Schrenk and Josef Xu, who made a valuable contribution to this research through their support in collecting data.

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