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Identification of Property Change Impacts Based on Requirements-Oriented, Multi-Criteria Decision Models

D. Horber ✉, B. Schleich and S. Wartzack
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
✉ horber@mfk.fau.de

Abstract
As an outcome of the multi-criteria evaluation of different alternatives, product developers receive information on whether the evaluation alternatives meet the demanded property profile. If not, product characteristic and property changes are required, which can have desired and undesired effects. This contribution presents an MBSE-based approach, which extends the relational requirement model by value functions and product properties. Its novelty can be found in the integration of multi-criteria decision models, which are used to improve alternatives based on property change impact analyses.

Keywords: decision making, requirements management, characteristics and properties, engineering change, model-based systems engineering (MBSE)

1. Introduction

In today's engineering design domain, new approaches are needed to address the growing complexity of modern products. For this purpose, new methods are being developed in the field of digital engineering, of which model-based systems engineering (MBSE) is an important subtype (Henderson and Salado, 2021). With MBSE, an approach is available that transforms the product development process from classical document-based development to model-based engineering and integrates heterogeneous models into a single source of truth, especially to avoid inconsistencies between models (Madni and Sievers, 2018). According to a study by Carroll and Malins (2016), the MBSE approach is primarily applied in requirements engineering and management. An essential advantage of it is the re-use of models and model elements, which on the one hand saves time for modeling when re-using previous models (Carroll and Malins, 2016), but on the other hand also ensures consistency between the models and thus guarantees continuous traceability (Madni and Sievers, 2018). This can not only avoid errors during development, but also reduce risks and associated costs (Henderson and Salado, 2021). In their study, Henderson and Salado (2021) also mention further benefits of MBSE application, but note that these are primarily perceived benefits.

A major challenge, however, is the additional modeling effort required for the introduction and implementation of MBSE approaches, which is why the goal of new approaches is to find a compromise between additional effort and benefits as well as to compensate this effort through technical utilization of system models (Wilking *et al.*, 2020). For this reason, this paper deals with the coupling of requirements and multi-criteria evaluation models as well as their extension to finally achieve the goal of using modeled requirement relations for the identification and analysis of desired property change impacts based on the multicriteria decision results. This enables product developers to adapt products to the demanded property profile. This profile is demanded by customers and must therefore be fulfilled by the product in order to be successful on the market later on. Due to complex dependencies, undesired

effects can occur in addition to desired effects, which significantly influences acceptance by customers and could lead to failure in the market.
In order to answer the research question of this contribution, namely how value-based relations can be used to identify and quantify property changes (see sec. 3), its structure is as follows. Building on the related work (sec. 2), the basics for the mathematical modeling of value-based relations ($\mathbf{Rel}_k$) are presented in sec. 4, which are necessary to develop the approach for property change impact analyses (sec. 5). In the following, this contribution focuses on the theoretical concept of the value-approach and therefore emphasizes the discussion of different strategies for its implementation. The explanation of the property impact analysis is divided into the basic approach (sec. 5.2) and the application to a use case (sec. 5.3), which is followed by a critical discussion of the results (sec. 5.4). The paper concludes with a summary of the developed results and an outlook on future research questions (sec. 6).

2. Related work

During a product's development, product developers have the option of setting the free design parameters in such a way that particular properties result in the later product. According to Weber (2005), these free design parameters are called characteristics ($\mathbf{C}_i$) and can be influenced by developers, e.g. the length of a component. Properties ($\mathbf{P}_j$), in contrast, result from the combination of one or more $\mathbf{C}_i$ and can therefore not be influenced directly, such as the aesthetics of a product (Weber, 2005). However, customers demand a certain property profile, so the main task of product developers is to make sure, that the product fulfills it. In the various decision situations along the development process, such as concept decisions (Krishnan and Ulrich, 2001), it is crucial, that this demanded property profile is represented via requirements ($\mathbf{Req}_m$) and goals ($\mathbf{G}_n$). In multi-criteria evaluation, the different alternatives can therefore be evaluated with regarding the fulfillment of this profile and a decision for an alternative can be made (Eisenführ *et al.*, 2010). If $\mathbf{P}_j$ are not fulfilled sufficiently, it is the task of developers to adapt the product accordingly and consequently make changes. However, changes do not only lead to desired effects, but also to undesired ones. Therefore, engineering change management is generally dealing with changes of all kinds in the development processes (Hamraz *et al.*, 2013). Impact assessment is the focus of this research area and considers not only impacts but also probabilities and risks of impacts (Clarkson *et al.*, 2004). The analyses of impacts can be performed at the component level (Koh *et al.*, 2012) or at lower levels, such as in the requirements model (Zhang *et al.*, 2014). In their case study, Zhang *et al.* (2014) investigated the practical application of requirements relations and how they can be used for change propagation analysis. Further use cases are provided in a comprehensive literature review by Ullah *et al.* (2016). The authors also show which different methods are used for modeling $\mathbf{Rel}_k$ for change propagation analysis and state that besides rarely used methods, such as SysML, matrix-based approaches using Dependency Structure Matrix (DSM) are primarily applied (Ullah *et al.*, 2016). Moreover, this method is also used by approaches that enable impact analysis of $\mathbf{C}_i$ (Köhler *et al.*, 2008). The overall approach is based on the definition of Weber (2005) including the characteristics-properties modeling (CPM) and property driven design (PDD) introduced in that paper as well as the change impact and risk analysis (CIRA) presented by Conrad *et al.* (2007). The state-of-the-art provides an important foundation for the analysis of change impacts for the purpose of this contribution as mentioned at the beginning of this paper. In particular, the connection between product $\mathbf{C}_i$ and $\mathbf{P}_j$ (Conrad *et al.*, 2007; Köhler *et al.*, 2008) provides an essential framework for this contribution. Nevertheless, the fundamental integration of the requirements model and evaluation model is missing in the analyzed approaches. As a result, there is a significant gap between these approaches and a model-based implementation is hindered. As a result, the consistent reuse of the pre-existing models is not possible, which obstructs the main idea behind MBSE approaches and consequently its benefits (see Henderson and Salado (2021)).

3. Research questions

The analysis and quantification of change impacts are an important aspect for the assessment of undesired effects on the developed product. The state of the art shows that impact analyses are already used in various areas, such as requirements management. For this purpose, existing models are extended in such a way that it is possible to draw conclusions about the effects of changes. The different model elements have to be related to each other with suitable **Rel**$_k$ and algorithms for the analysis must be developed. In addition to that, the fundamental concept in MBSE is also that existing models are reused in order to improve the benefits of modeling and thus compensate the modeling effort that was invested (Wilking *et al.*, 2020). In the field of decision-making, an impact analysis is not yet available, which enables the identification of property changes based on decision results. Motivated by the challenges and the lack of a suitable approach, this paper therefore addresses the question of how **Rel**$_k$ can be used in a multi-criteria decision model to identify and quantify property changes. In addition, this contribution deals with a second question, which concerns how **Rel**$_k$ have to be modeled in order to be able to provide a quantitative conclusion about the change effects.

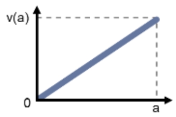
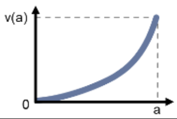
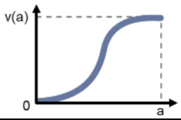
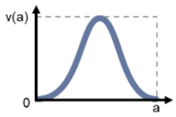
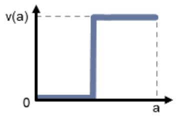
4. Value Model and value-function-based relation modeling

In this section, the fundamentals of a value-based modeling approach will be explained, which will form the foundation for the following concept. The focus is on the mathematical description of these **Rel**$_k$ and the underlying modeling approach. The goal of using this approach is the possibility to provide a quantified conclusion about the effects of changes. Therefore, the basic model for decision making will be defined first. According to Eisenführ *et al.* (2010), the additive model is well suited for multidimensional decision problems in which different objectives or attributes must be considered for a decision. In its general form, the additive model is calculated as follows (Equation 1):

$$V(a) = \sum_{i=1}^{m} w_i * v_i(a_i) \tag{1}$$

In this equation, i describes the number of different attributes in the decision model. Since several attributes usually have to be taken into account, Eisenführ *et al.* (2010) use the term multi-attributive value functions. In addition, each attribute has an individual weighting w_i, where the sum of all individual weights must equal 1. The value of each attribute is calculated using the value function v_i and the actual measure of an alternative a_i and aggregated per alternative into the value V(a), which enables the comparability of different alternatives in the context of decision making. For the characterization of value functions, different function types can be identified, which appear in product development (see Table 1). These can be adapted to the preferences of decision makers (**DMs**) with the variations listed in Table 1. These functions can be used to normalize the different **C**$_i$ to a defined measure.

Table 1. Common value functions appearing in product development (based on (Breiing and Knosala, 1997) and (Eisenführ *et al.*, 2010))

Value Function	Type and basic formula	Variations
	Linear Functions $v(a) = x * a$	min-/max-values; positive or negative gradient;
	Exponential Functions $v(a) = x * a^b$	min-/max-values; positive or negative gradient; digressive or progressive;
	Sigmoid Functions $v(a) = sig(a)$	min-/max-values; positive or negative gradient; position of turning point;
	Optimum Functions $e.g.: normal\ distribution$	min-/max-values; positive or negative gradient; position of optimum point;
	Heaviside Function $v(a) = \begin{cases} 0: a < t \\ 1\ \ a \geq t \end{cases}$	position and direction of hurdle point;

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A common value function is the linear function, which describes the linear relationship between the measure of an attribute to the normalized value. However, if the preference of **DMs** differs in the sense that the shape of the function is relevant, then exponential or sigmoid functions can be used. For example, when each kilogram of weight saved in the entire system becomes increasingly important for achieving the target. Optimum functions are used when an attribute has an optimum, for example, a planned target weight. The Heaviside function is used when there is a hurdle that must be overcome, but fulfillment beyond that hurdle offers no further added value.

For decision making, value function-based modeling is a useful method for mapping preferences of **DMs** (Eisenführ *et al.*, 2010). The definition of the value has an essential importance in this context. In the approach mentioned before, the value maps preferences of **DMs**. However, other approaches also use value-based modeling for different applications, such as calculating a quality loss (Phadke, 1989) or in multi-criteria evaluation methods (Breiing and Knosala, 1997). For this reason, an explicit definition of the value is necessary prior to modeling to ensure that all developers create value functions on the same understanding. In the following, the mathematical side will not be discussed in more detail, but the approach and its implementation in this contribution will be explained on a broader level.

5. Value-function-based Property Change Impact Analysis

The property profile demanded by customers' needs to be taken into account during development and the product to be tailored accordingly. In practice, however, no perfect product solution is possible, since $\mathbf{P}_j$ cannot be adjusted to all extend due to complex dependencies between $\mathbf{C}_i$. Instead, these dependencies become apparent in such a way that an increase in $\mathbf{P}_1$ may lead to a decrease in $\mathbf{P}_2$. In the best scenario, this dependency is desired and the $\mathbf{P}_j$ in concern is positively affected. However, these changes can also result in undesirable effects on dependent $\mathbf{P}_j$. For this reason, it is essential for developers to obtain an understanding of the potential effects of adjustments to the property profile, for example through visual representations (Figure 1).

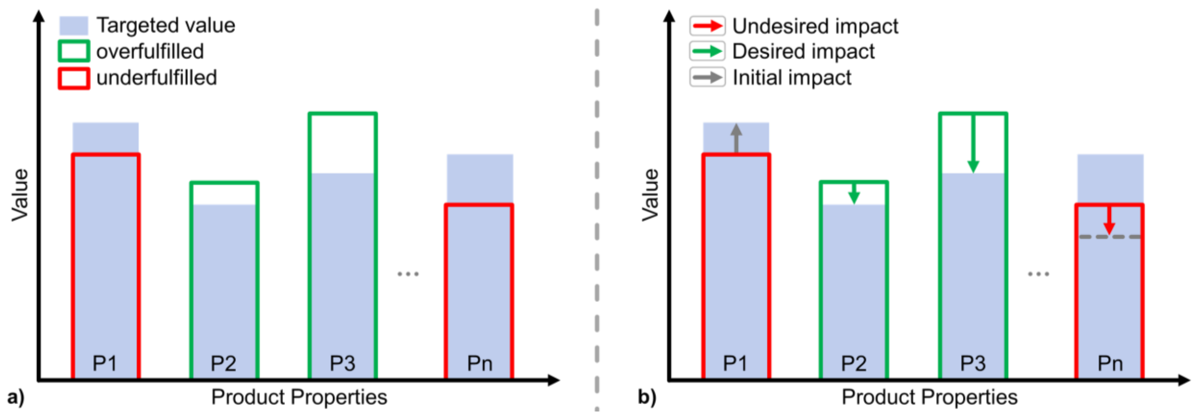

Figure 1. Exemplary property profile of a product concept: target and actual values (a) and desired as well as undesired property change impacts (b)

It shows on the left side (a) an exemplary property profile (blue) as well as the underfulfillment (red) or overfulfillment (green) by a product alternative. When product developers adjust the $\mathbf{C}_i$, $\mathbf{P}_1$ for example, can now be improved (b), which results in a reduction of $\mathbf{P}_2$ and $\mathbf{P}_3$. This is a desired effect since both property values are overfulfilled. Yet, other $\mathbf{P}_j$ can be affected negatively, which the product developer may not identify. This needs to be considered in decision making as soon as $\mathbf{P}_j$ are intended to be changed after evaluation. For this reason, it is necessary to support product developers adequately and therefore modeling strategies will be presented and discussed in the following, which enable an impact analysis based on the mentioned $\mathbf{Rel}_k$.

5.1. Strategies for value modeling in requirements-oriented decision making

A variety of different decisions need to be made along the product development process (Krishnan and Ulrich, 2001). In the context of multi-criteria decision-making, a model is necessary that contains the

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relevant criteria. Requirements-oriented decision-making is an approach in which the criteria are derived (semi-) automated from requirement elements already during their specification process (Horber *et al.*, 2020). Thus, the $\mathbf{Req}_m$ are directly linked to the evaluation model and can be used for decision-making. In addition, superordinate $\mathbf{G}_n$, which address the $\mathbf{P}_j$ of the later product, are integrated into the decision-making process. In this approach, the $\mathbf{Req}_m$ however are related to the $\mathbf{C}_i$, since they can be manipulated by the product developers. Different $\mathbf{Rel}_k$ between the $\mathbf{Req}_m$ usually occur based on the related product $\mathbf{C}_i$, which can be identified and qualitatively modeled with the procedure presented by Horber *et al.* (2021). Here $\mathbf{Rel}_k$ of the type dependency, condition, structure and relationship can be considered, whereby the latter provides the foundation for the approach presented in this contribution. The $\mathbf{Rel}_k$ of the type relationship describe the influence of dependent $\mathbf{Req}_m$ through direction and intensity (Horber *et al.*, 2021). The missing link between the $\mathbf{P}_j$ and $\mathbf{C}_i$ has to be modeled in order to obtain a consistent link between $\mathbf{Req}_m$ and the $\mathbf{G}_n$. Accordingly, a total of three modeling strategies can be proposed for value-function-based modeling (see Figure 2). With type 1 only $\mathbf{Rel}_k$ between $\mathbf{Req}_m$ and $\mathbf{G}_n$ are created, whereas type 2 considers the $\mathbf{P}_j$ additionally. Type 3 extends the model and integrates product $\mathbf{C}_i$. The three strategies are analyzed regarding value function-based modeling in more detail in the following and their suitability is discussed.

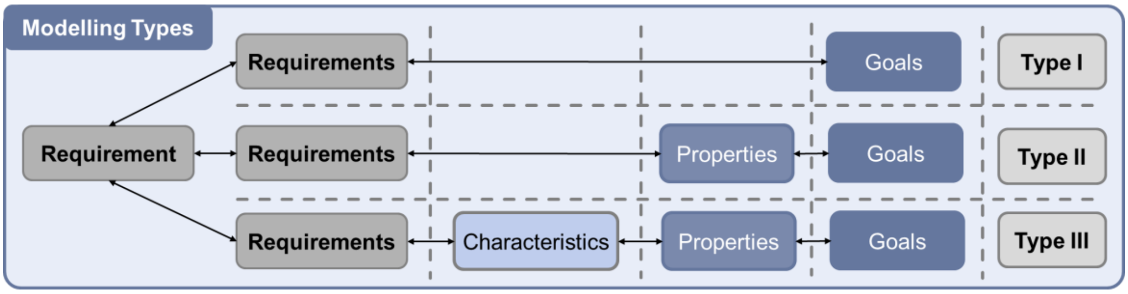

Figure 2. Modeling types for value-function-based relations

5.1.1. *Analysis of value modeling strategies*

Based on the modeling types shown in (Figure 2), the potential $\mathbf{Rel}_k$ that are required to map dependencies between the relevant model elements for each type can be analyzed in more detail. As explained in Section 4, it is essential for the value function-based modeling that the corresponding value is defined. Therefore, the potential relation types, the value definitions and the corresponding references are summarized in Table 2.

Table 2. Different relations based on the proposed modeling types

Relation Type	**Value definition**	**Reference**
Requirements ↔ Goals	Goal fulfillment	Requirement
Properties ↔ Goals		Property
Requirements ↔ Properties	Property fulfillment	Requirement
Characteristics ↔ Properties		Characteristic
Requirements ↔ Characteristics	Characteristic fulfillment	Requirement

A differentiation of the $\mathbf{Rel}_k$ regarding value modeling may be conducted, which distinguish each other by the fulfillment of a goal, a $\mathbf{P}_j$ or a $\mathbf{C}_i$. Depending on the relation type, the corresponding references have to be considered, too. The value function for goal fulfillment has to contain requirement as a reference for $\mathbf{Rel}_k$ between $\mathbf{Req}_m$ and $\mathbf{G}_n$, whereas the reference $\mathbf{P}_j$ has to be considered between $\mathbf{P}_j$ and $\mathbf{G}_n$. Consequently, the modelled value functions differ fundamentally, which is why this distinction is mandatory. In the following, the types of relation modeling will be discussed in order to evaluate their suitability for impact analysis.

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5.1.2. Discussion of value modeling strategies

When selecting one of the three modeling types, it is important to consider essential factors such as the theoretical model completeness and the necessary modeling effort. The completeness gives a first outlook on the theoretical quality of the model, since a more exact representation of the possible and existing $\mathbf{Rel}_k$ offers a more detailed analysis and more comprehensive conclusions on influences can be drawn. However, the factor of apparent accuracy must be taken into account, which means that a certain accuracy is implied by the quantity of modeled $\mathbf{Rel}_k$. However, this depends heavily on how confident product developers are in modeling the $\mathbf{Rel}_k$ and how accurately they correspond to reality. For this reason a compromise must be found for the selected modeling strategy, which enables a high theoretical completeness but also accuracy. In the following an example for the qualitative discussion of the modeling types is used. With 10 relevant $\mathbf{Req}_m$ and respectively $\mathbf{C}_i$, 3 related $\mathbf{P}_j$ and accordingly $\mathbf{G}_n$, a varying number of $\mathbf{Rel}_k$ have to be modeled for each modeling type. These are shown in (Figure 3) and provide the foundation for the qualitative diagram.

Type	Relation from	...to	max. number of relations
Minimum effort	Requirements	Requirements	10 x 9 = **90**
Type I	Requirements	Goals	10 x 3 = **30**
Type II	Requirements	Properties	10 x 3 = **30**
	Properties	Goals	3 x 3 = **9**
Type III	Requirements	Characteristics	10 x 1 = **10**
	Characteristics	Properties	10 x 3 = **30**
	Properties	Goals	3 x 3 = **9**

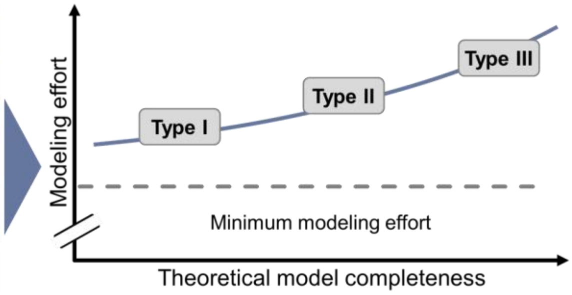

Figure 3. Calculation of maximum number of relations and derivation of the qualitative correlation of modeling effort and theoretical degree of model completeness

In general, a minimal modeling effort exists that results from the requirements modeling and the mapping of interrelations and dependencies between requirement elements as presented by Horber *et al.* (2021). This is unavoidable and covers the majority of the potential $\mathbf{Rel}_k$ that need to be checked and, if necessary, modeled and results in 90 possible ones in this example. Type 1 also includes possible $\mathbf{Rel}_k$ between $\mathbf{Req}_m$ and $\mathbf{G}_n$, which enable the assessment of the essential fulfillment of the $\mathbf{G}_n$. In this case, 30 $\mathbf{Rel}_k$ are possible, since each $\mathbf{Req}_m$ could be related to each goal. However, a major disadvantage here is that neither $\mathbf{P}_j$ nor $\mathbf{C}_i$ are taken into account. For this reason, this type is not suitable for a property change impact analysis. Type 2 extends the modeling by $\mathbf{P}_j$, therefore $\mathbf{Rel}_k$ between $\mathbf{Req}_m$ and $\mathbf{P}_j$ as well as between $\mathbf{P}_j$ and $\mathbf{G}_n$ can be considered. The 10 existing requirement elements can be related to the 3 possible $\mathbf{P}_j$, with a maximum of 30 $\mathbf{Rel}_k$ needing to be modeled. On the other hand the $\mathbf{P}_j$ are assigned to the 3 superordinate $\mathbf{G}_n$, whereby each $\mathbf{P}_j$ refers potentially to each goal. Therefore, a maximum of 9 further $\mathbf{Rel}_k$ would have to be modeled. The disadvantage of Type 2, is that the $\mathbf{C}_i$ are explicitly or implicitly included in the requirement statements and not modeled separately. Therefore, the identification of the $\mathbf{Rel}_k$ and also their traceability is more difficult, since no information is documented for the review of them. For this reason, it is recommended and necessary to model $\mathbf{C}_i$ separately and to link them to the $\mathbf{Req}_m$ with 1:1 relations. This is possible with the modeling strategy of the third type. The additional effort is not significantly increased, in the presented example there are just 9 additional $\mathbf{Rel}_k$. Now product developers can model all $\mathbf{Rel}_k$ between $\mathbf{Req}_m$, $\mathbf{Req}_m$ and $\mathbf{C}_i$, $\mathbf{C}_i$ and $\mathbf{P}_j$ as well as $\mathbf{P}_j$ and $\mathbf{G}_n$. This enables a consistent impact analysis between all model elements and is therefore necessary for the approach presented in this contribution.

5.2. Extended requirement and relation model

In this section, the main model for property impact analysis is presented. This builds on the requirements-oriented decision-making process proposed by Horber *et al.* (2020) and the included derivation of requirement elements in order to consistently apply them in the evaluation model. Furthermore, the procedure for relational modeling of product requirements presented in Horber *et al.* (2021) and the proposed relational model are essential for this contribution. For this reason, the preliminary work is extended by the concept of property change impact analysis, as shown in (Figure 4).

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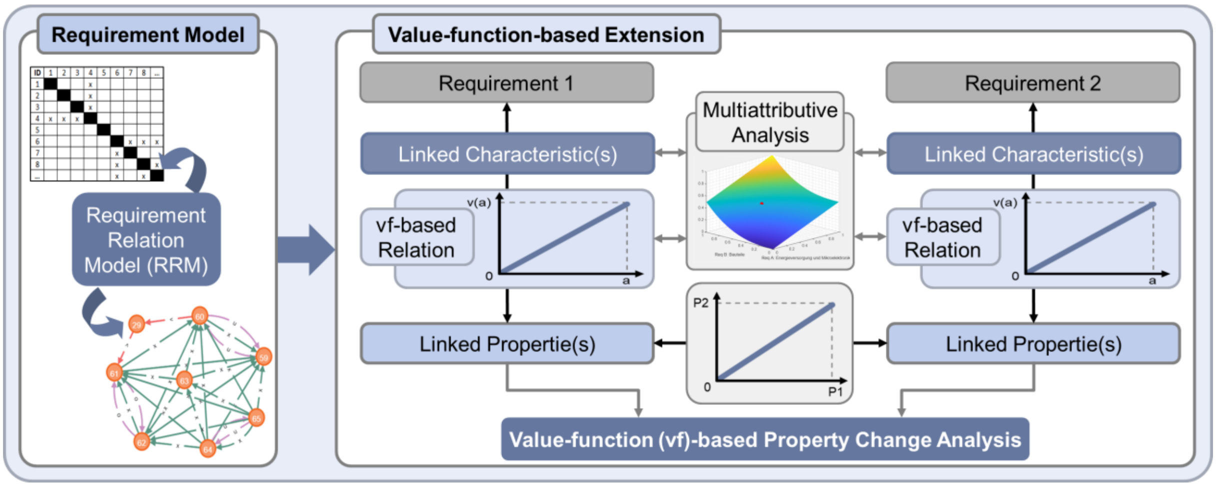

Figure 4. Value-function-based analysis of dependent requirements and their related characteristics and properties (extended from Horber *et al.* (2021))

Based on the previously conducted analysis of modeling strategies (see section 5), the third type is used for modeling, since it offers the best ratio of modeling effort and expressiveness due to the theoretical degree of fulfillment of the relational model. The requirement relation matrix (**RRM**) included in Horber *et al.* (2021) is used to utilize the modeled $\mathbf{Rel}_k$ and use them for the property change impact analysis. Only those requirement elements are considered which have been derived as optimization criteria for multi-criteria evaluation, since they have an evaluative character in contrast to selection criteria. Selection criteria are not used, because they are only checked for fulfillment and non-fulfillment and are therefore not suitable for an influence analysis. In the presented approach the modeled $\mathbf{Rel}_k$ between $\mathbf{Req}_m$ of the type relationship as well as their extension by direction and intensity are used, which describe the qualitative or quantitative impact of the $\mathbf{Req}_m$ based on linked $\mathbf{C}_i$. In this contribution they can now be extended with more detailed value functions, which enables a better representation of the interactions between them. The $\mathbf{Req}_m$ are then assigned to existing $\mathbf{C}_i$ with 1:n relations. The $\mathbf{C}_i$ are assigned afterwards with value function-based $\mathbf{Rel}_k$ to the products $\mathbf{P}_j$, which are derived from superordinate $\mathbf{G}_n$ and likewise connected with 1:n relations. This ensures that the requirements model is linked consistently to the goal model and that this information can be made available throughout the product development process. For example, superordinate $\mathbf{G}_n$ are less likely to be forgotten and $\mathbf{Req}_m$ are not misinterpreted without the related $\mathbf{G}_n$. The modeling of $\mathbf{Rel}_k$ between $\mathbf{C}_i$ and $\mathbf{P}_j$ also allows the multiattributive analysis of interrelations between them based on the additive approach presented before (see section 4). This is visually represented in (Figure 4) and shows a positively directed $\mathbf{Rel}_k$ of two $\mathbf{C}_i$ to the same $\mathbf{P}_j$. The multi-attribute analysis primarily supports product developers in obtaining a quick overview of the existing $\mathbf{Rel}_k$ to a product $\mathbf{P}_j$ and in assessing how it might be influenced by linked $\mathbf{C}_i$ in order to achieve a desired impact. For the property change impact analysis, the existing $\mathbf{Rel}_k$ from the **RRM** can now be used to derive the impact assessment between two $\mathbf{P}_j$ via the linked $\mathbf{C}_i$ and their influence on the $\mathbf{P}_j$. In the example shown in (Figure 4), this is symbolized with a linear $\mathbf{Rel}_k$ between the two $\mathbf{P}_j$. In reality, however, this interaction follows a more complex interrelation and results from the sum of the value functions as well as the modeled $\mathbf{Rel}_k$ with their direction and intensity between the $\mathbf{C}_i$.

In summary, the presented approach will now be positioned in the product development process. Product developers define all product requirements with the tool presented by Horber *et al.* (2020) and derive them in evaluation criteria. Using the process model of Horber *et al.* (2021), requirement relations can now be modeled in the **RRM** and used for the development of alternatives. The graph-based visualization of the **RRM** is also available as a support for this task. As soon as a decision situation is faced, for example for one of the concepts, the derived criteria are used for multi-criteria evaluation. For this purpose, it is necessary to model $\mathbf{Rel}_k$ between $\mathbf{P}_j$ and $\mathbf{C}_i$ through value functions, which enable the evaluation on the fulfillment of the property profile. In case alternatives and the corresponding $\mathbf{P}_j$ have to be adjusted, relations between the relevant $\mathbf{P}_j$ must be specified in a multiple-domain matrix. This specification is done via the direction and intensity of the impact and enables the conversion into a value

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function. Subsequently, these $\mathbf{Rel}_k$ can be analyzed specifically, for example by graph-based visualization. As a result, (un-)desired impacts on the property profile can now be quantified and developers can decide whether a property change will improve an alternative in terms of the evaluation results or not. Therefore, it enables developers to improve decision alternatives based on the demanded property profile. In the following, the applicability of the approach will be demonstrated in a use case.

5.3. Use Case

The use case covers a development project for the improvement of a steering and folding mechanism for an electrified transport vehicle for individual mobility in urban environments. The requirements model comprises 50 requirement elements and therefore also criteria, whereby 11 criteria were derived as optimization criteria and 39 as selection criteria following the approach of Horber *et al.* (2020). The goal of the multi-criteria evaluation is to decide on one of the alternative product concepts for the steering mechanism. The focus here, however, is on the application of the presented approach. Therefore, the execution of the multi-criteria evaluation is not part of this use case. Instead, the focus is on relational modeling using value functions and analyzing the change impact of desired property changes. For this purpose, a tool was developed that supports the modeling and parameterization of value functions listed in section 4 between $\mathbf{C}_i$ and $\mathbf{P}_j$ (see Figure 5).

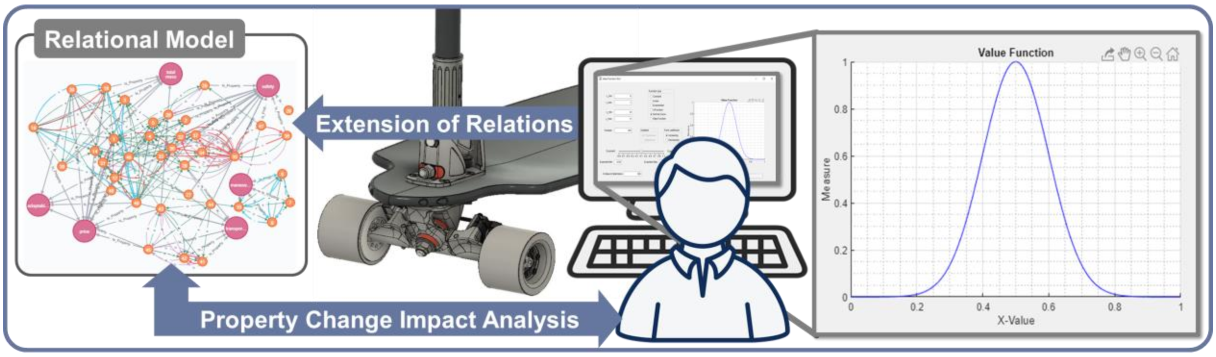

Figure 5. Tool-supported value function modeling (right side) and relational model enabling property change impact analysis (left side) of the electrified transport vehicle (middle)

After defining the $\mathbf{G}_n$, six different $\mathbf{P}_j$ were derived from them, relating to the maneuverability ($\mathbf{P}_1$), transportability ($\mathbf{P}_2$), adaptability ($\mathbf{P}_3$), safety ($\mathbf{P}_4$), price ($\mathbf{P}_5$) and total mass ($\mathbf{P}_6$) of the product. The relation modeling was reduced to linear value functions in order to represent the $\mathbf{Rel}_k$ between the $\mathbf{C}_i$ and $\mathbf{P}_j$. For the use case, the analysis of $\mathbf{P}_2$, $\mathbf{P}_3$, $\mathbf{P}_5$ and $\mathbf{P}_6$ is now examined in more detail first. The $\mathbf{C}_i$ that positively influence the transportability property ($\mathbf{P}_2$) have a negative influence on the mass ($\mathbf{P}_6$) and the price ($\mathbf{P}_5$) of the product. This includes, for example, the $\mathbf{Req}_{45}$ "Time for folding and unfolding shall be <= 3 seconds", since a fast and simple mechanism requires a stable and therefore heavy, cost-intensive solution. In this case, safety ($\mathbf{P}_4$) is also an important product $\mathbf{P}_j$, since such a mechanism must nevertheless fulfill all safety-related requirements. If an alternative should now be improved in terms of $\mathbf{P}_2$ in order to enable even faster opening and closing of the vehicle, the identified $\mathbf{Rel}_k$ have to be taken into account. $\mathbf{P}_4$ is also influenced by $\mathbf{C}_i$ assigned to $\mathbf{Req}_9$ "Board tilt angle during cornering with minimum turning circle shall be >= 15° and <25° (optimum 20°)" and $\mathbf{Req}_{10}$ "Maximum control rod deflection shall be >= 15° and <30° (optimum 25°)". At their highest values, these $\mathbf{C}_i$ have a reduced level of safety, since, for example, excessive deflection of the control rod during maximum cornering can lead to an unsafe stance on the vehicle. However, the $\mathbf{C}_i$ assigned to the two requirement elements have a positive effect on maneuverability ($\mathbf{P}_1$), with each of these having an optimum value for property fulfillment. This corresponds to an s-shaped value function, as shown in (Figure 5) (right-hand side).

Overall, the use case showed that the basic idea of the presented approach and the visualization options can support product developers and desired and undesired changes can be identified. In addition, in the presented use case, the combination of different solution concepts can also be used to improve that alternative which will be realized in further product development. For example, partial solutions for the folding and steering mechanism can potentially be combined, generating a better solution overall. In the

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decision-making process, this solution consequently scores higher, although it must be critically examined whether a combination is technically possible. The developed modeling tool also assists in the parameterization of the value functions, as users are provided with a direct visual representation for the currently selected parameters. This is especially necessary for normalization of the $\mathbf{C}_i$, as the parameters can differ significantly with different ranges of according measures.

5.4. Discussion

The goal of this contribution is to assist product developers to identify desired property changes and their impacts. This also includes negative or undesired effects on other $\mathbf{P}_j$, which can lead to a product that does not succeed in the market. This approach is therefore not intended to compute an optimal product, since it is in doubt whether this optimal product is also technically realizable or it possibly does not fulfill other $\mathbf{G}_n$ or $\mathbf{Req}_m$. These include manufacturing requirements or even more wide-ranging $\mathbf{Req}_m$ such as the sustainability of a product. In addition, the modeling extent has a major influence on the accuracy of the model. If, for example, relevant $\mathbf{P}_j$ are not taken into account, or if important relationships between $\mathbf{P}_j$ are forgotten, it is not possible to identify the resulting impacts or changes on related $\mathbf{C}_i$. In general, the uncertainty of relation modeling has a significant influence on the results of the impact analysis. Ideally, product developers are aware of all $\mathbf{Rel}_k$ and can convert them into an appropriate value function (Eisenführ *et al.*, 2010). Factors such as the experience of product developers or the availability of relevant data also have an influence on this circumstance. Overall, the concept presented for change and impact analysis provides a suitable basis for identifying desired and undesired impacts and supporting product developers in this process. However, there is a strong dependency between the number of model elements and the effort required for modeling. The presented approach is an extension of a multi-criteria evaluation model, which is used for decision making anyway. For this reason, this model only has to be extended by missing aspects, which reduces the effort significantly. In addition, it is decreased in projects that deal with the modification of existing products and thus models that have already been created can be reused and only need to be adapted. Another use case is offered by generalized evaluation models, such as for the evaluation of the sustainability of evaluation alternatives, since defined criteria and $\mathbf{P}_j$ are used for evaluation and therefore only a mapping to product $\mathbf{C}_i$ has to be done. Despite this, there is great potential in reducing modeling effort; for example, when $\mathbf{Req}_m$ with containing explicit or implicit $\mathbf{C}_i$ are classified using Natural Language Processing (NLP) and matched using a database, whereby value function-based $\mathbf{Rel}_k$ and their parameterization are suggested. Götz *et al.* (2021) already apply this in an approach in the context of robust design for the assignment of quality loss functions, but this approach still requires further development.

6. Conclusion and future work

The continuous trend from mechanically characterized products to mechatronic systems requires new approaches, which, due to the increasing complexity, are supported by model-based approaches such as MBSE. An essential aspect of this is the connection and reuse of models. For this reason, this paper deals with the reuse of the multi-criteria evaluation model, which is consistently linked to the requirements model existing approaches. The present contribution focuses on the advancement of the **RRM** for its use in property change impact analysis based on a value function-based modeling approach. In the presented approach, $\mathbf{Rel}_k$ between $\mathbf{Req}_m$, $\mathbf{C}_i$, $\mathbf{P}_j$ and $\mathbf{G}_n$ are considered, whereby the $\mathbf{Rel}_k$ between $\mathbf{C}_i$ and $\mathbf{P}_j$ are refined by value functions. With this approach, the two research questions are answered, which extends the multi-criteria decision model to be used for the identification of desired and undesired property change impacts. In summary, the connection of the evaluation model and its reuse contributes to the utilization of system models, enabling a purpose beyond just documentation and visualization. In addition, the combination of the models causes positive benefits, because now changes in the requirement model can be transferred directly into the evaluation model and into the relational model to the $\mathbf{P}_j$ and $\mathbf{C}_i$. Consequently, modifications are applied consistently and are not forgotten in related models. The applicability of the proposed approach was shown exemplarily in a use case. Based on a critical discussion of the results, it can be stated that the general functionality is provided, but some aspects still need further research. For example, the reduction of effort for relation modeling or the question of how qualitative interrelations can be taken into account in this quantitative model.

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