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MATRIX-BASED SYSTEM MODELLING TO PREDICT PROPERTIES CHANGE PROPAGATION

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Abstract

A significant shorter pre-development time in the automotive industry without physical prototypes due to a quicker generation of concepts is key to reduce development cost and to reach a higher product maturity much faster. However, especially appropriate product property changes have to be considered and can be handled better while reducing the number of macro-iterations and, instead, fostering micro-iterations in order to support a more agile development process. Consequently, it is inevitable for the application of an agile development and change management process to apply a holistic system consideration and to widen the range of consideration along the complete development process and not to stick in the determination of details. In this contribution, an approach towards a matrix-based system model is presented which applies both a systemic and systematic process upon the modelling of a whole system. The multi-dimensional mathematical description of the system elements and the hierarchical system decomposition support the calculation in a top-down / bottom-up procedure. Special attention is given to the product property changes and their propagation throughout the system.

Keywords: Design for X (DfX), Design to X, Product modelling / models, Multi-dimensional optimization, Property change propagation

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1 INTRODUCTION

A quicker generation of concepts in the automotive industry without physical prototypes or less virtual prototypes can lead to a significant shortening of pre-development time, and thus to a sharper increase of product maturity. As a consequence, however, appropriate product property changes need special consideration and finally can be handled better and almost just-in-time when additionally applying an agile change management procedure. In this way, it is possible to vastly reduce the number of macro-iterations as they are known in conventional product development methodologies and process models and, instead, to foster micro-iterations in the product development process which are more desirable due to both the agility during the design process and faster decision making.

Consequently, it is inevitable for the application of an agile development and change management process to apply a holistic system consideration and to widen the range of consideration along the complete development process, and hence not to stick in the determination of details.

Matrix-based product development methods, e.g., the use of the Design Structure Matrix (DSM) and the Domain Mapping Matrix (DMM) (Luft and Wartzack, 2016) or the Axiomatic Design introduced by Suh (1990), could offer the required holistic system consideration and provide the opportunity to describe the design process in a mathematical-logical way. Nevertheless, there are some essential deficiencies within these approaches, especially with regard to the insufficient multi-criterial optimization and the consistent description of the design process.

In this contribution, an approach towards a matrix-based system model is presented which applies both a systemic and a systematic process upon the modelling of a whole (system). After recapitulating the state of the art in section 2, the modelling process is introduced in section 3 based on previous publications by the authors. Limitations, going along with focusing on the aspect of one-dimensional weight reduction, are overcome by widening the range of affection towards multi-criterial and simultaneously multi-dimensional changes of product and system properties. Therefore, the inter-correlated influence of change propagations among each system elements has to be considered. Moreover, section 4 depicts the application of the approach in a two-dimensional criteria system (i.e. weight and cost) along with the consideration of lightweight zones, which are well-known in the automotive industry. Possible further influences on the system beside the ones considered in the example, such as sustainability or cross-component aspects (i.e. material selection), could be easily integrated into the approach.

2 STATE OF THE ART

2.1 Change Propagation of Product Properties

According to Clarkson et al. (2001), changes in design occur unexpectedly in about five to fifty percent of all cases. This includes altered requirements, but also unexpected difficulties in finishing the design process as the most frequent reason for changes becoming necessary. In doing so, Clarkson et al. (2001) differentiate between three types of systems: total-absorbers contribute to full absorbance of changes, absorbers partially annihilate changes and carriers only lead to propagation of changes without being affected on their own. The correlations between systems and sub-systems can be assessed by design structure matrices and change propagation trees, as presented in (Clarkson et al., 2001). In order to predict secondary changes of system properties, Clarkson et al. (2001) developed a Change Prediction Method which is based upon the DSM representation of a system structure and the calculation of a predictive matrix. Combined with risk management techniques, the method allows forecasts of possible changes resulting from initial alterations. Accordingly, and originating from this approach, Luedeke et al. (2014) developed a description method where a vertical and horizontal hierarchy is applied to the proposed system. In it, different system levels are used to vertically describe the partial structure and relations within the system as a whole, whereas the lowest system level is the component level. In the horizontal hierarchy the system has to be reordered following the importance of weight or function. The approach presented by Luedeke et al. (2014) can be applied to different fields of interest. In both approaches a multi-criteria assessment and optimization is not yet considered, which causes a lack of complexity management ability, particularly with regard to the aforementioned main deficit of existing approaches (see section 1).

2.2 Matrix-Based System Modelling - CPM/PDD-Approach and Axiomatic Design

Considering the approach proposed in former publications by the author, the question arises, why the specific system-view is matrix-based. Eichinger et al. (2006) emphasize the capability of matrix-based approaches to give “a concise visualization of complex network structures” (Eichinger et al., 2006). This can be done by setting up Design Structure Matrices (DSM) (Steward, 1981) and Domain Mapping Matrices (DMM) (Danilovic and Browning, 2004), but also by correlation of customer preferences and product properties, as proposed by Clausing (1994). The use case of DSM/DMM concepts is not only limited to product or system properties and characteristics according to the CPM/PDD-approach of Weber (2005), but can also be used to model the relations between RFLP-elements, referring to Luft and Wartzack (2016). Specifically, matrix-based approaches are able to capture full relation-sets between properties and characteristics according to Weber (2005). Based on this point of view, it becomes even more obvious, that with a mathematical theory behind a systematic approach the assessment of relations and changes can be performed much more efficiently and effectively (i.e. changes and effects become traceable (Luft and Wartzack, 2016) due to automatization possibilities regarding the use of computer-based tools. Regarding different approaches towards matrix-based system representations, Axiomatic Design comes to mind. In the research contributions of Suh (1990) a design theory based on the correlation of functional requirements (FR) and design parameters (DP) through a design-matrix ($\underline{\boldsymbol{A}}$) is presented. Combined with two axioms (independence axiom and information axiom) the aim of his theory is to determine the optimum solution for the desired system. Suh (1990) differentiates between uncoupled designs ($\underline{\boldsymbol{A}}$ is a diagonal matrix), decoupled designs (only the lower ranks of $\underline{\boldsymbol{A}}$ are unequal zero) and coupled designs, where the entries of $\underline{\boldsymbol{A}}$ are possibly all unequal zero. In doing so, uncoupled designs shall be preferred in terms of fulfilling the independence axiom; however, typical engineering systems have to be considered as coupled designs for different reasons, primarily caused by complexity and interdependencies between system elements. In a second step, the information stored in the design shall be minimized. Regarding matrix-based approaches in general and Suh's Axiomatic Design in particular, the CPM/PDD-concept of Weber (2005) has to be inevitably mentioned as well. There are significant similarities between the two concepts, such as the immediate comparability of functional requirements and Weber's properties, but also design parameters basically corresponding to characteristics. Regarding engineering design changes and change propagation, Köhler et al. (2008) presented a matrix-based approach in which the CPM/PDD-theory was used as a framework of the change impact analysis. The description of change impacts is stated in a rather general way, which shall be intensified by mathematical formulations in order to formalize the process of change impact determination. However, both approaches, the Axiomatic Design and CPM/PDD, are afflicted with deficits to reliably handle complex systems and inherent changes by means of change management. Nevertheless, the mean concept provides some potential and a solid basis for advanced instrumentalization of the approaches.

2.3 Secondary Weight Propagation

There are different (i.e. top-down and bottom-up) approaches considering secondary weight propagation. Alonso et al. (2012) and Bjeklengren (2008) focus on the determination of secondary weight saving potentials by analytically calculating them from rudimentary assumptions on the component level. This procedure can be used in the early stages of system development and can be categorized as top-down because changes on system level are used to determine possible results on the sub-system. Referring to Clarkson et al. (2001), various defined types of sub-systems can be compared to absorbers and carriers. Besides Alonso et al. (2012) and Bjelkengren (2008), Eckstein et al. (2010, 2011) developed a systematic determination method based on pre-defined criteria, by which sub-systems and components are measured in terms of weight saving potentials. Criteria used in this approach are size, forces and moments of inertia (Luedeke, 2016). Referring to the automotive industry, Trautwein et al. (2011) developed a model in which primary saving efforts are to be minimized causing a maximum of secondary savings. This approach is, like Eckstein's, characterized by estimations. Luedeke (2016) presents a first approach in which systemic and systematic processes are used in order to maximize weight saving potentials.

3 APPROACH TO A SYSTEMIC PROPERTY CHANGE PROPAGATION METHOD

3.1 Overall Approach and Prerequisites / Requirements

The approach presented here is based on the work of the authors for the systematic determination of secondary weight improvements; see Luedeke and Vielhaber (2014), Luedeke et al. (2014) and Luedeke (2016). Thereby, not only weight improvements, but also changes of related properties, i.e. the trade-offs of weight improvements, will be focused.

The transition from the one-dimensional problem of weight improvements (ordinary number) to the multi-dimensional description of property changes (matrix system) sets up different requirements and prerequisites, which have to be considered:

- clear, simple and hierarchical definition of the system
- identification of the interdependencies between different system elements
- take-over of the mathematical rules from the approach to systematic determination of secondary weight improvements (Luedeke, 2016)

Thus, the core issues of the approach are:

- possibility to apply a multi-criterial property change, i.e. a weight improvement or a change of the geometric shape, in all system levels
- systematic and systemic identification of system element interdependencies and interrelations between the different system elements to achieve a higher system knowledge
- possibility to detect and analyze the secondary effects of property change (so-called secondary property changes)
- managing and monitoring this change propagation throughout the system and during the design process
- easy understanding of the system structure
- simple search for solutions and possible trade-offs or side effects

3.2 System Model Approach

The starting point for the approach has to be the description of every single system element as shown below (see Figure 1).

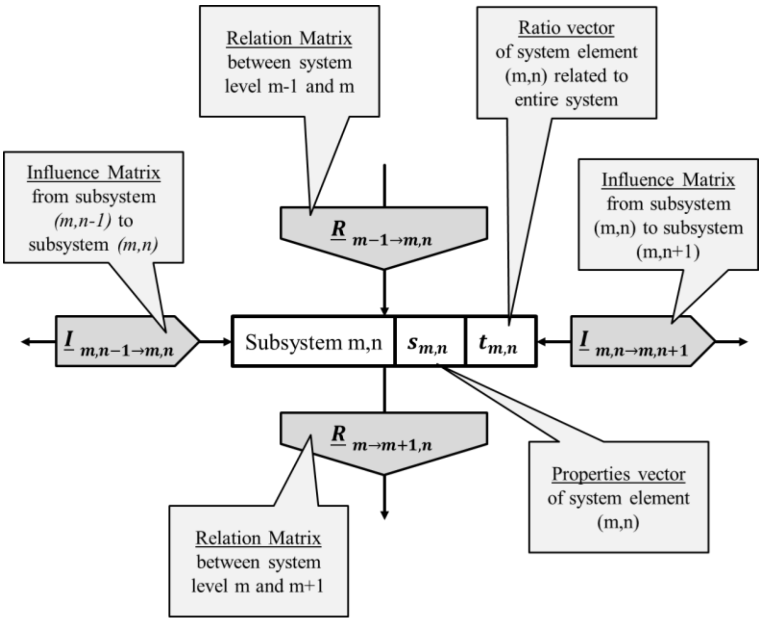

Figure 1. Description of one single system element

The n-th subsystem on system level m can be described as the vector $\boldsymbol{s}_{m,n}$ wherein all properties are depicted as scalar quantities. The vector $\boldsymbol{t}_{m,n}$ shows the scalar properties as a ratio relation to the total system vector. Additionally, on the one hand, the matrices $\underline{\boldsymbol{R}}_{m-1\to m,n}$ or rather $\underline{\boldsymbol{R}}_{m\to m+1,n}$ and $\underline{\boldsymbol{I}}_{m,n-1\to n}$

or rather $\underline{\boldsymbol{I}}_{\boldsymbol{m,n\rightarrow n+1}}$ show the interdependencies between the different system elements, and on the other hand, in a vertical way between the system elements in different system levels and between system elements in the same system level.

Table 1. Symbols and Explanations

Symbol	Explanation
$p_{m,n}^{i}$	property *i* of system element *n* on system level *m*
$\delta p_{m,n}^{i}$	change of property *i* of system element n on system level *m*
$\lambda p_{m,n\rightarrow m,n+k}^{i}$	influence of property *i* from system element *m,n* on system element *m,n+k*
$\underline{\boldsymbol{\Delta}}_{\boldsymbol{m,n}}$	change matrix applied on system element *n* on system level *m*
$\underline{I}_{m,n-1\rightarrow n}$	influence matrix from system element *n-1* to *n* on system level *m*
$\underline{R}_{m-1\rightarrow m,n}$	relation matrix from system level *m-1* to *m* in relation to system element *n*
$\boldsymbol{s}_{\boldsymbol{m,n}}$	vector of properties of system element *n* on system level *m*
$\boldsymbol{s}_{\boldsymbol{m,n}}^{*}$	updated vector of properties of system element *n* on system level *m*
$\boldsymbol{t}_{\boldsymbol{m,n}}$	vector of the ratios of properties of system element *n* on system level *m* related to the entire system

The process of property changes can be described as illustrated in Figure 2. Contrary to the matrix-based representation of the CPM-/PDD-model (Köhler et al., 2008), where the characteristics are connected with a dependency matrix, the herein presented approach focuses on the mathematical description and procedure for property changes. Thus, the system, subsystems, and consequently their properties are connected with the corresponding influence matrices and factors. However, it is assumed that the system structure is already known.

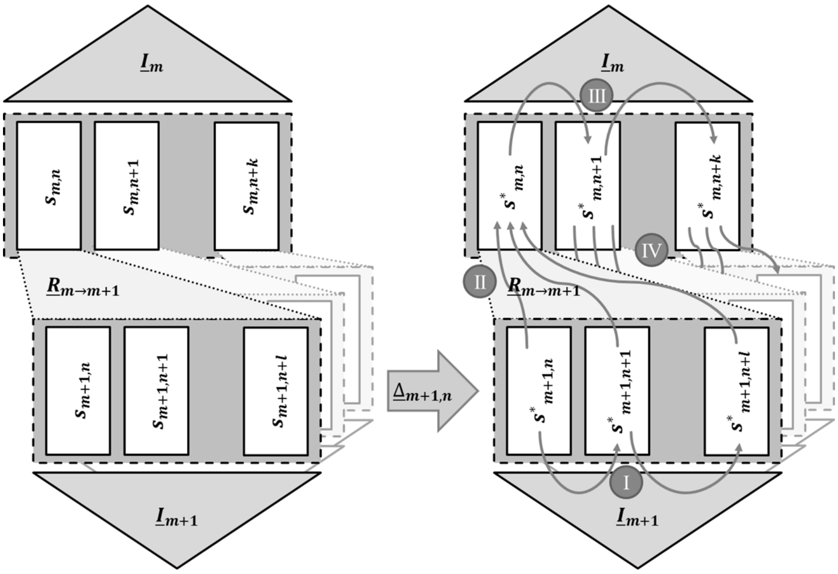

Figure 2. Matrix-Based System Model in original condition (left), Matrix-Based System Model with property changes influenced by the change matrix $\underline{\boldsymbol{\Delta}}_{\boldsymbol{m+1,n}}$ (right)

Based on the hierarchical structure and a decomposition of the system into subsystems, e.g. according to Shishko et al. (2007), every subsystem is characterized by a set of properties. In doing so, the subsystems derived from the same subsystem in a higher system level are becoming one single limited subsystem group in which the influence matrix is connecting them; see for example Luedeke (2016). Thus, the linked higher-level subsystem is related to the subsystems via the property relation matrix. It has to be stated that only properties which are directly influenceable by characteristics are considered in the mathematical description. They can be easily broken down and allocated to different system elements, for example weight, cost or functionality. Moreover, there are properties which can be derived from these direct properties, for example velocity or acceleration. They can only be influenced indirectly by characteristics since they are affected by changes of direct properties. These indirect properties only appear on the highest system level and have to be separated from the direct properties which are

considered in detail. It is necessary to translate indirect properties into a set of direct properties in the mathematical approach, for example velocity can be expressed as a combination of the sum of masses/weights of the single subsystems, the acceleration force and the time instead of acceleration and time.
Due to the application of a change matrix to a specific subsystem (see step (I) in Figure 1) - that means changing at least one property which describes this system element - the change in properties in the other subsystems of the subsystem group can be derived via the influence matrix. All the changes of these subsystems being added up and combined with the relation matrix result in a property change of the superior subsystem (II). The horizontal change in that prior level (III) is done in the same way like before in step (I). Based on that, the vertical distribution to subsystems in a lower system level (IV) is conducted top-down with the inherent relation matrix.

3.3 Multi-Dimensional Mathematical Description

The vector for the arbitrary system element n on system level m can mathematically be assumed with the number z of properties as follows (noted that these properties are already known at this point of the design process).

$$\boldsymbol{s_{m,n}} = \begin{pmatrix} p_{m,n}^1 \\ p_{m,n}^2 \\ \vdots \\ p_{m,n}^z \end{pmatrix} \tag{1}$$

The change of one property of this system element leads to a change of the properties in this system element (provided that they are dependent on each other, e.g. cost and weight) and to other system elements on different system levels. Thus, the change matrix for the primary property changes can be written as follows, wherein $\delta p_{m,n}^i$ describes the change factor of property $p_{m,n}^i$.

$$\underline{\Delta}_{\boldsymbol{m,n}} = \begin{pmatrix} \delta p_{m,n}^1 & 0 & \cdots & 0 \\ 0 & \delta p_{m,n}^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & \delta p_{m,n}^z \end{pmatrix} \tag{2}$$

Based on the change of the properties, the aforementioned system element vector can be determined as follows

$$\boldsymbol{s_{m,n}^*} = \underline{\Delta}_{\boldsymbol{m,n}} \cdot \boldsymbol{s_{m,n}} = \begin{pmatrix} \delta p_{m,n}^1 & 0 & \cdots & 0 \\ 0 & \delta p_{m,n}^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & \delta p_{m,n}^z \end{pmatrix} \cdot \begin{pmatrix} p_{m,n}^1 \\ p_{m,n}^2 \\ \vdots \\ p_{m,n}^z \end{pmatrix} = \begin{pmatrix} \delta p_{m,n}^1 \cdot p_{m,n}^1 \\ \delta p_{m,n}^2 \cdot p_{m,n}^2 \\ \vdots \\ \delta p_{m,n}^z \cdot p_{m,n}^z \end{pmatrix}. \tag{3}$$

The influence matrix from system element $\boldsymbol{s_{m,n}}$ on the system element $\boldsymbol{s_{m,n+k}}$ can similarly be determined with the influence factors described in Luedeke (2016). It results from the multiplication of all influence matrices between system element (m,n) to $(m,n+k)$, so to say the product from the influence factor from (m,n) to $(m,n+1)$, influence factor from $(m,n+1)$ to $(m,n+2)$ and so on. The scalar influence factor from property i from system element (m,n) to $(m,n+k)$ is defined as $p_{m,n\to m,n+k}^1$.

$$\underline{\boldsymbol{I}}_{\boldsymbol{m,n\to m,n+k}} = \underline{\boldsymbol{I}}_{\boldsymbol{m,n\to m,n+1}} \cdot \underline{\boldsymbol{I}}_{\boldsymbol{m,n+1\to m,n+2}} \cdot \ldots \cdot \underline{\boldsymbol{I}}_{\boldsymbol{m,n+k-1\to m,n+k}} = \prod_{i=1}^{k} \underline{\boldsymbol{I}}_{\boldsymbol{m,n+i-1\to m,n+i}} \tag{4}$$

$$\underline{\boldsymbol{I}}_{\boldsymbol{m,n\to m,n+k}} = \begin{pmatrix} \lambda p_{m,n\to m,n+k}^1 & 0 & \cdots & 0 \\ 0 & \lambda p_{m,n\to m,n+k}^2 & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & \lambda p_{m,n\to m,n+k}^z \end{pmatrix} =$$

$$\begin{pmatrix} \prod_{i=1}^{k} \lambda p_{m,n+i-1\to m,n+i}^{1} & 0 & \cdots & 0 \\ 0 & \prod_{i=1}^{k} \lambda p_{m,n+i-1\to m,n+i}^{2} & \cdots & 0 \\ \vdots & \vdots & \ddots & 0 \\ 0 & 0 & 0 & \prod_{i=1}^{k} \lambda p_{m,n+i-1\to m,n+i}^{z} \end{pmatrix} \quad (5)$$

Finally, the description of a system element $(m, n + k)$ and the changed system element $(m, n + k)$ is as follows

$$\boldsymbol{s}_{m,n+k} = \underline{\boldsymbol{I}}_{m,n\to m,n+k} \cdot \boldsymbol{s}_{m,n} = \prod_{i=1}^{k} \underline{\boldsymbol{I}}_{m,n+i-1\to m,n+i} \cdot \boldsymbol{s}_{m,n} \quad (6)$$

$$\boldsymbol{s}_{m,n+k}^{*} = \underline{\boldsymbol{I}}_{m,n\to m,n+k} \cdot \boldsymbol{s}_{m,n}^{*} = \underline{\boldsymbol{I}}_{m,n\to m,n+k} \cdot \underline{\Delta}_{m,n} \cdot \boldsymbol{s}_{m,n} = \prod_{i=1}^{k} \underline{\boldsymbol{I}}_{m,n+i-1\to m,n+i} \cdot \underline{\Delta}_{m,n} \cdot \boldsymbol{s}_{m,n} \quad (7)$$

Thus, the system element and their change are dependent on the one system element where the change happens. The change is propagated throughout the system level in a horizontal way. The propagation in a vertical way up to system level $(n - 1)$ is defined with the summarization of the single system elements belonging to this prior subsystem and multiplication with the specific related proportion from the matrix $\underline{\boldsymbol{R}}_{\boldsymbol{m-1\to m,n}}$. Consequently, the description of the system element in system level $(n - 1)$ results in equation (8), where the operation has to be considered an addition of direct properties, which can in any case be considered summable in a mathematical kind of way.

$$\boldsymbol{s}_{m-1,\mathbf{p}} = \sum_{j=0}^{k} \boldsymbol{s}_{m,n+j} \, . \quad (8)$$

Analogically to the mathematical approach in previous publications of the authors, the procedure is conducted until all the system elements are considered and the highest system level is reached.

3.4 Prioritization of Weight - Lightweight Zones

Due to the increasing complexity of future vehicle concepts, a weight reduction including a simultaneously economic efficiency can only be achieved by a targeted selection of lightweight measures (i.e. material or conceptual lightweight design) with the most promising cost-benefit ratio (Ellenrieder et al., 2013). Therefore, in particular within automotive lightweight design, the question arises of how much costs are justified in terms of saving one kilogram of weight. However, these vary considerably regarding both the different areas of application (e.g. up to 500-1,000 €/kg in aviation versus 3-14 €/kg in automotive industry (Ellenrieder et al., 2013; McKinsey&Company, 2012) and the respective position of the structural part inside the overall structure. Concerning the spatial distribution of elements, the target values for additional costs within a certain vehicle concept depends on the type of drive and drive constellation and, subsequently, its dominant location along with the overall center of gravity (Kopp et al., 2011). Figure 3 depicts exemplarily the case of a rear drive with a drive unit in the vehicle front.

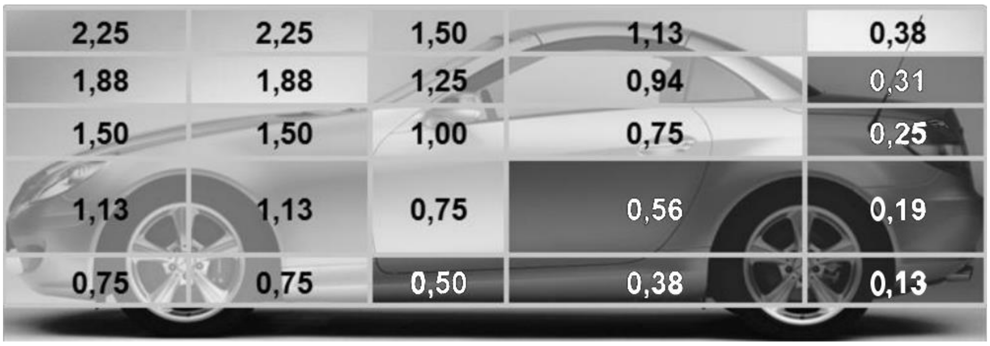

Figure 3. Reference values (so-called efficiency factors) of permitted additional lightweight costs depending on its lightweight zone (Ellenrieder et al., 2013)

Thus, the geometrical determination and definition of different lightweight zones (defined horizontally by the desired axle load distribution and vertically by lowering the center of gravity) lead to an appropriate knowledge base for decision support in order to meet the demand for cost-effective lightweight design and avoidance of secondary weights while at the same time optimizing the vehicle dynamics (Ellenrieder et al, 2013). As a result, and due to the driving dynamics linked with the

associated center of gravity, an efficiency factor is allocated according to their effectiveness to achieve the goal, whereby higher efficiency factors (> 1) for weight reduction lead to acceptable costs for weight reduction in the front and roof area (indicated in green/light grey) rather than in the rear of the car (indicated in red/dark grey).
Consequently, the cluster approach of lightweight zones provide an important decision-making support due to their traceable functional logic particularly regarding the prioritization of lightweight measures, even though a comprehensive assessment of the final concept and technology determination cannot totally be replaced.

4 ILLUSTRATIVE APPLICATION EXAMPLE

To evaluate the aforementioned thoughts and mathematically formulated interdependencies, an illustrative application example of a structural module (assembly) in the front part of a car is hereinafter exemplified for the two criteria (i.e. two-dimensional matrix) of weight and costs. For this purpose, the initial system is built up in a top-down manner as shown in figure 4.

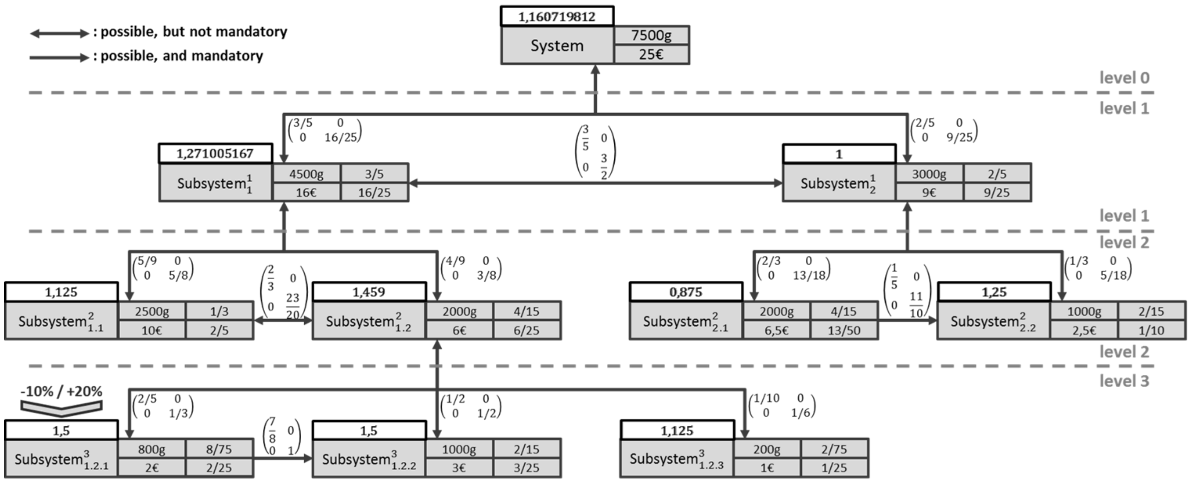

Figure 4. Initial system of matrix-based property change propagation corresponding to weight and costs

According to Figure 2, the two-dimensional matrix being displayed above the respective single system element indicates the affected relation matrix $\underline{\boldsymbol{R}}_{\boldsymbol{m-1\to m,n}}$. Similarly, the left and right-hand two-dimensional influence matrices $\underline{I}$ present the interdependencies between the different system elements. In contrast, however, the right-hand side of a single element is divided into four parts concerning the two criteria of weight and cost propagation throughout the entire system. Further dimensions with respect to more different criteria would successively enlarge these entries of the matrices.
However, to get a good indication for the starting point of appropriate (material, technological or conceptual) lightweight measures, first the hierarchical system is classified into their actual lightweight zones (blue/dark grey marked boxes). Thus, starting with a primary property change (yellow/lightest grey marked), secondary changes (green/ darker grey marked) in weight and costs are applied to adjacent subsystems on the same level by the individual change factor of property $\delta p^i_{m,n}$.
Thus, regarding the illustrative example mentioned here, the primary measure (-10% decrease of weight, +20% increase in costs) immediately decreases the weight of $Subsystem^3_{1.2.1}$ to 720g (originating from 800g), while at the same time increasing the costs by 0.40€. Subsequently, these changes imply, on the one hand, a weight reduction of 8.75% (10% multiplied by 7/8) on $Subsystem^3_{1.2.2}$ and, on the other hand, an increase in costs by unchanged 20%, see Figure 5. Corresponding impacts on $Subsystem^3_{1.2.3}$ do not exist, which lead to no property changes regarding this element at all.
After this individual calculation of property changes within the subsystem level 3, the total secondary changes in weight and costs can be summed up, and thus result in the comprehensive $Subsystem^3_{1.2}$. Thereafter, the same procedure as described above takes place on subsystem level 2, i.e. the secondary property changes interacting with $Subsystem^3_{1.1}$, and then also up to level 1. In the end, the resulting (changed) values are split according to their weighting and independent of further secondary measures for the right-hand $Subsystem^3_2$.

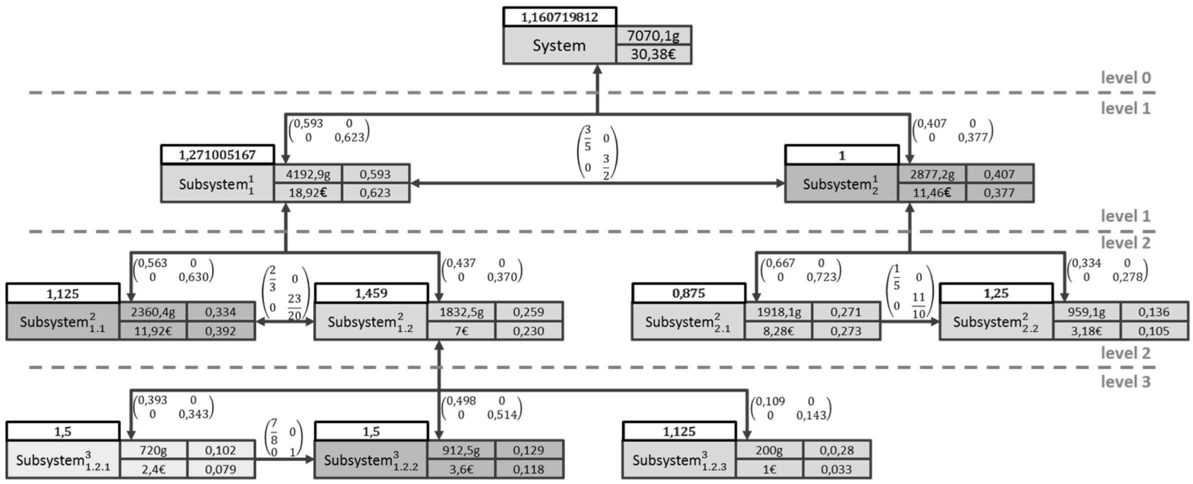

Figure 5. Executed system of matrix-based property change propagation corresponding to weight and costs as well as prioritization due to lightweight zones

5 CONCLUSION & OUTLOOK

The presented approach offers a systematic and systemic procedure for the determination of property change propagations. Considering a matrix-based system modelling, including relations between system levels and influences within the system levels, property changes can quickly be determined and specific property-changing measures can be taken in order to lead the properties and, thus, the system towards the required functionality and performance. The mathematical description of the system elements and relations as well as the hierarchical system decomposition supports the simple calculation in a top-down and bottom-up procedure.

Based on this, the authors already initiate efforts focusing on the sustainable extension of the matrix-based approach (Kaspar et al., 2017) as well as the prioritization of specific property changes in the form of a prioritization matrix, i.e. more attention has to be paid to weight instead of costs due to a specifically desired product performance. The determination of a characteristic key index for the comparison of different change matrices is also part of current activities, for example, how to compare change matrices with different prioritization of properties and their influence on the system and the system behavior.

In consideration of further work, however, the implementation of this matrix-based modelling to other abstraction levels (requirements, functions, working principles) is also of great interest. The modelling process on the functional abstraction level enables the developer to distribute the entire system functionality to sub-functions which can be automatically mapped to solutions patterns. These solutions patterns represent the abstraction level of working principles. The matrix-based mapping of customer functions and technical functions shows the link between customer requirements and general functions. Additionally, scenario techniques have to be applied and adapted in the model to show different cases of changes (best-case scenario or worst-case scenario) when one specific system element is affected by more than one other system element on the same system level.

An approach to the transition of customer requirements to technical (i.e. measurable) requirements which are synthesized to the product properties and, thus, the correlation between customer requirements to final product properties seems reasonable. Finally, this also applies to cross-component aspects regarding an integrated view of product design, material and process selection (Kaspar and Vielhaber, 2016).

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