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SYSTEMATIC DETERMINATION OF SECONDARY WEIGHT IMPROVEMENTS

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1. Introduction

Sustainability poses a key challenge to current and future product development. Creating sustainable, environmental conscious and resource efficient products is a common goal of today's engineers. Operationalization of this goal is however challenging and often requires multidimensional optimizations across complex product systems. It is therefor not inherently integrated into development processes, methods and tools, yet. One approach often associated with sustainability and environmental goals is lightweight design or, more precise, weight-optimized design. Weight optimization is one example for a multidimensional optimization where changing one factor may lead to unforeseeable secondary effects on multiple related system elements.

Weight optimization requires technological and material oriented competences as well as methodical approaches to make new technologies and materials applicable in engineering designs, first, and to manage weights and weight impacts across complex product systems, second. If done properly, weight optimization can lead to an optimized resource efficiency across the life cycle and thus build an important cornerstone in an overall framework for sustainable product engineering. Thus, it seems inevitable to consider the task of weight optimization during the product development process.

Traditional lightweight design concepts realizing weight improvements during the design process is not sufficient anymore. Lightweight design methodologies offer different lightweight strategies and measures which are often applied to single components or parts late or at the end of the design process. They mainly take place on a physical level of the product. The more abstract system levels (for example functional or principle solution level) are however not considered. Moreover, the proposed measures (primary weight improvements) mostly achieve success on component level without regarding consequences for the whole system/product. This often results in an over-dimensioning of the surrounding structure of the lightened component. Iterations in the design process for re-designing this surrounding are often time- and cost-extensive.

Several approaches for the identification and handling of the possible additional weight improvements come from the automotive and aeronautical sector where systematical procedures for these so-called secondary weight improvements are established (see [Alonso 2012], [Eckstein 2010], [Eckstein 2011] [Trautwein 2011]). The approaches of [de Weck 2006] and [Bjelkengren 2008] assume that for a detailed analysis of the secondary weight optimizations a better understanding of system and subsystem mass interdependencies and a quantification of subsystem-specific mass decompounding effects are crucial. The core problem of these approaches is however that they are mostly limited to the physical structure of products.

In this contribution, the authors propose a holistic approach for the identification and handling of primary and secondary weight improvements. When weight improvement measures are applied the determination of weight change impact factors is in special focus.

2. Background

2.1 Primary and secondary weight potentials

Traditional lightweight strategies (for example material lightweight design, conceptual lightweight design, structural or manufacturing lightweight design) offer direct weight optimization methods for selective components or subsystems. The application of these primary weight saving measures are the starting point and the trigger for the application of secondary weight optimization measures. In this optimization step these secondary methods allow a further weight improvement. In this case the applied measures refer to components, parts or subsystems which are connected to the subsystem optimized before [Eckstein 2010, 2011]. As example serves an automobile: if it is possible to reduce the entire vehicle mass by substituting the material of the body-in-white, the other main subsystems (for example engine, brakes, gearbox, …) are oversized in terms of weight and performance. As a secondary weight improvement step, these subsystems are redesigned considering lightweight aspects.

2.2 Literature study on secondary weight potentials

A literature study has been conducted. Most of the references dealing with secondary weight potentials are existing in the industry sectors of automobiles and aircrafts.

The contribution of [de Weck 2006] presents a system approach considering a so-called "mass budget management" during early design phases, especially for new complex vehicles and products. In contrary to traditional mass budget management approaches with a hierarchical system decomposition followed by top-down mass allocations to subsystems and components it is assumed that interactions within subsystem level have to be taken into account. That is why it is not sure how mass optimizations in one subsystem lead to deterioration in parallel subsystems. Moreover, the handling of uncertainty when allocating mass to subsystems in early design phases must be considered as well as systematic methods for decomposing and assigning the mass to individual subsystems. During conceptual design the system mass drivers must be determined and an overall system mass must be estimated, both derived from the system requirements set. A helpful step is to map the key performance requirements against the key system variables. The mass allocation to the subsystems and components is supported by Systems Engineering tasks (tracking total mass, allocation to subsystems, deriving the mass sensitivity, systematical procedure). Moreover, an integrated system model is set to capture both the key performances as well as total system mass as a function of system level design variables. Open issues of the approach of de Weck are the impact of the degree of modularity on system mass, the impact on mass savings on lifecycle cost and the management of mass increases during retrofits or upgrades.

The paper of Alonso et al. [2011] and the contribution of Bjelkengren [2008] propose a method extending the traditional empirical estimation of secondary weight savings to an analytical estimation which quantifies the uncertainty in the estimation and the importance of expert classification of data at component level for managing the mass-independent effects as well as characterizes the inherent upper-bound bias of this method. The method focuses on the early design phases during the development process in the automotive sector. The method aims to infer subsystem mass changes due to a change in general system mass (top-down process) that means how the potential of secondary weight optimizations (here in subsystems) is correlated to primary weight optimizations (here in the system as a whole). It is assumed that the mass of each component/subsystem is a function of system mass. But the components can be classified in mass-independent and mass-dependent whereat independent means that the mass of the component is not a direct response to change in overall system mass. With a mathematical description and simulation the mass influence and dependency of subsystem and components on the overall system is estimated. The mass decompounding coefficients describe this estimation. Bjelkengren [2008] assumes that a detailed analysis of these secondary mass optimizations necessitates a better understanding of the subsystem mass interdependencies and a quantification of the subsystem-specific mass decompounding effects.

Eckstein et al. [2010, 2011] proposes an approach for an empirical and analytical determination of the secondary weight reduction, especially for passenger cars. Shown on an example, the car is structured in its subsystems (body, chassis, engine and drive train, interior equipment and automobile electronics)

for identification of the components which are relevant for the secondary weight reduction. Following this general car classification the components with a secondary optimization potential are identified with the aid of predefined selection criteria which are a function of dimensioning, driving power and forces of inertia. Based on this selection analytical and empirical interrelations between required component property and gross vehicle mass are determined. Finite element simulations supply the result of weight reduction of the entire car.
The holistic approach of Trautwein et al. [2011] has been developed in the automobile sector. The proposal achieves its full secondary mass potential when the dimensioning framework is specified before the design of any part is done or any supplier query is requested. Aim is to minimize the efforts of primary lightweight measures by implementing secondary mass effects as numerous as possible. The proceeding of the approach starts with determining the strategic target weight, comes to an anticipation of secondary mass effect and derivation of the required primary mass saving impulse as well as the definition of the required mass of all components or subsystems and finishes with the final dimensioning and the design of the vehicle.

2.3 Gaps in research

To sum up, all these approaches and methods found in the literature study are sharing the same objective: estimating the potential of secondary weight measures on an empirical or analytical way. Because of considering mostly the physical part of a system (subsystems and components) and neglecting the other abstraction levels with functional structure and principal structure (working structure) when regarding secondary mass effects and applying suitable measures some shortcomings arise concerning a holistic application of the secondary weight improvements throughout the whole development process. The authors aim to fill these gaps and propose an approach with a holistic application of primary and secondary weight optimization measures and additionally the possibility for monitoring weight properties and weight propagation throughout the design process and throughout the system.

3. Approach for secondary weight improvements

3.1 General process model

The process model [Luedeke 2013a, 2013b] offers a holistic management of weight properties throughout the whole development process starting with the task setting and requirements and finishing with the real product. The approach for managing and monitoring is to introduce analysis gates both between and within the main design process steps product planning and task setting, conceptual design as well as embodiment and detail design.
The stage of conceptual design serves as a first estimation and rough calculation of the weight properties as well as an overview for crosslinks and interdependencies within the system and subsystems which can result in further weight propagation. After substantiation of the system concept in an important analysis gate, the final layout and design of the system and its subsystems is performed in the detail and embodiment design stage which ends with another analysis gate providing a very detailed value of the future weight properties.
Moreover, the different design stages are developed in sense of mechatronic design. Thus, the known process model for mechatronic design (V model) as well as the stages system design, domain-specific design and system integration are reflected within the different steps of conceptual and detail design. It has to be stated that the V models in the stages are similar to the 3-level process model of Bender [2005]. It is divided into different levels: system level, subsystem level and component level.

3.2 Approach

Based on the literature review given above the principles of secondary weight optimizations are compound in a holistic approach which is integrated into the process model for the development of weight-oriented mechatronic products, published by the authors in former contributions [Luedeke 2013a, 2013b]. In this contribution, the conceptual design phase will be focused.

3.2.1 Design process in conceptual design phase

The conceptual design phase generally follows the known process model of mechatronic design (VDI 2206) [VDI 2004], but is adapted with analysis gates and thus micro-iterations between as well as the possibility for interdependencies detection. In the model of the conceptualization, three different system levels are illustrated: system level, subsystem level and component level. The procedure is shown in detail in Figure 1. During the conceptual design a concept for the entire system and based on this, concepts for subsystems and components are generated. Hence, the focus of this phase is not placed on a domain-specific view with high level of detail but more on the whole system and its subsystems with a lower level of detail. For the detailed procedure, see [Luedeke 2013b].

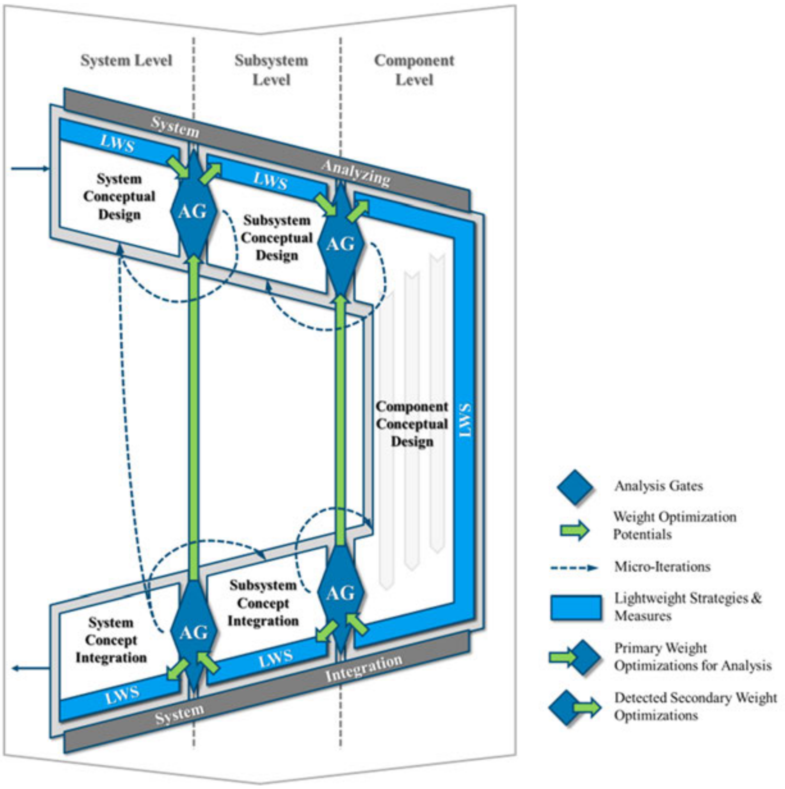

Figure 1. Conceptual Design Phase

Special attention has to be paid to decomposition and partitioning of the system main functions to subsystem functions which are consisting of function blocks. With their aid, a possibility is given to get to know the weight interdependencies and crosslinks between system and subsystems. The introduction of weight impact factors aims to specify these weight interdependencies. During the partitioning activity, care should be taken that the links to each other are not too complex and too numerous. For simple decomposed systems – i.e. systems with only hierarchical structure – the weight interdependencies are easily to determine.

With the help of a systematic application of the occurring lightweight strategies (systemic and conceptual lightweight design), it is capable to identify primary and secondary weight optimization potentials in this stage and when changing to the subsystem level. This means that (primary) optimization in system level provides further optimization in the system and subsystem levels (secondary optimization). A review of the weight properties is performed immediately after finishing this design stage.

With the integration of the component solutions to the subsystem level, interdependencies and crosslinks, relevant for weight properties and distinguished in the design step, between or rather within the subsystems are identifiable and calculable. During this integration step, the impact factors are adapted to the system. Thus, it is possible to apply measures for primary and secondary weight improvements which can result in a revised subsystem design stage and/or design cycle for components concepts. Based on the renewed subsystem concepts the system concept is achieved through another integration of the subsystem. Again, incompatibilities relevant for the weight properties can be identified and secondary weight optimizations realized.

3.2.2 Core issues of the approach

The weight optimization of the system as a whole is of superior importance against the weight optimization of individual parts of system (subsystems or components). Thus, the impact of applied lightweight measures in individual system parts on the overall system performance/weight has to be taken into account. A permanent monitoring of these weight impacts and thus secondary weight optimizations as well as the weight propagation throughout the system is crucial.
Further core issues of this approach are:

- Possibility to apply (primary and secondary) weight optimization methods in all abstraction levels during the design process (from requirements over functional structure, working principles, working and physical structure) and in all system level (system – subsystem – component)
- Systematical identification of weight interdependencies and interrelations within the system structure to gain higher system knowledge and a possibility to detect and analyze secondary weight improvements
- Possibility to apply decomposition and integration methods for implementing secondary weight optimizations during design process
- Managing and monitoring weight properties and weight propagation throughout the system during the design process

3.2.3 Decomposition and weight impact factors

The decomposition of a system into subsystems and further into components significantly influences the potential of weight optimization of the system. It is useful to distribute into subsystems or components with practical interfaces between and within the different system levels. That means that the decomposition top-down has to be done as simple as possible in order not to increase the complexity of the system. During the decompounding process a weight impact index is allocated because it can be assumed that there is no simply hierarchical distribution but inter-system level interdependencies.

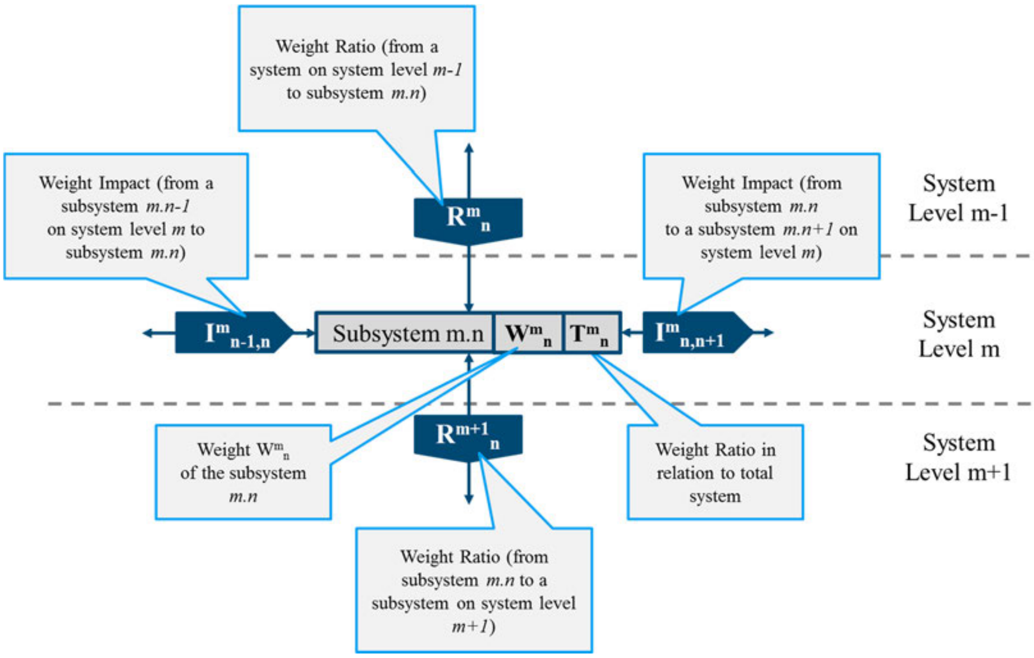

Figure 2. Subsystems, Weight Impact Indices and Weight Ratios

The Weight Impact Index $I^m_{n,n+1}$ – whereat index m is the system level and the index *n,n+1* the direction of weight impact (from subsystem n to *n+1*) – determines the weight impact of one subsystem to the other subsystems in one system level (horizontal).

In analogy to the objectives tree with evaluation criteria and a relative contribution [Pahl 2007] the weight of subsystems and components can be set in relation to the system on next higher system level and thus to the system as a whole.

With these two factors and the weight ratios R^m_n (percentage of weight on the system level depending on the superior system) and T^m_n (percentage of weight in proportion to the total system), the complete system is covered with a mathematical description of weight changes and dependencies. On the one hand, the total system weight is possible to be determined and on the other hand the weight propagation throughout the system and thus possibilities for a secondary weight optimization can be detected when a primary weight improvement on one subsystem/component is applied.

3.2.4 Prerequisites and limitations for the calculation method

In this calculation procedure, there are some limits and rules which have to be in mind:

- The order of the subsystems in the system structure tree is important. The subsystem with the highest mass is always on the left-hand side, the subsystem with the lowest mass on the right-hand side. However, the importance of functions of these subsystems also has to be taken into account. Thus, the order of the subsystems is an optimum of weight and function. With this order "possible" and "obligatory" weight improvements are arising. That means that a horizontal connection from left to right (from subsystem with higher weight to subsystem with lower weight) within one subsystem group and one system level – thus a possible weight improvement – automatically implicates an obligatory weight improvement from subsystem with lower weight to subsystem with higher weight.
- Weight ratios to the total system (T^m_n) which are under a certain limit are negligible. The estimation of these limit differs from application to application and has to be carried out.
- The handling of simultaneous weight gains and savings in a subsystem in one certain system level through the influence of two different weight impact factors to neighboring subsystems must be in consideration and in special focus.
- The calculation is restricted to simply hierarchically built systems. A method for more complex systems – i.e. systems with no simple hierarchy and with direct dependencies between subsystems – is more difficult and will be explained in further contributions.

3.2.5 General procedure for the determination of secondary weight improvements

Based on the decomposition and the system structure with weight ratios and weight impact indices the general procedure for the determination and the mathematical description of secondary weight improvements is as follows. The calculation first considers the weight of single subsystems, then the weight of a subsystems group and finally the weight of a system level. It has to be taken into account that the secondary weight improvements first are calculated in a subsystem and its related subsystem group. In this context a subsystem group is defined as all subsystems which are dependent on the same subsystem on the next prior system level. With the weight ratios determined the value of improvement is transferred to the next prior system level and then horizontally calculated in this system level in the same way as before. The single calculation steps are as following:

1. <u>Primary Weight Improvement Measure</u>:
   With the application of a primary measure in subsystem *m.1* (weight saving potential P^m_1) within a subsystem level m an improved weight W^{m*}_1 in this subsystem is determined.

$$W^{m*}_1 = W^m_1(1 + P^m_1) \tag{1}$$

2. <u>Secondary Weight Improvements in Subsystems</u>:
   The secondary weight savings S^m_n (dependent from the primary measure P^m_1) in the same hierarchical system level are calculated with the known weight impact factors. Thus, the improved weight of the subsystems can be determined.

$$\mathrm{S}_{\mathrm{n}}^{\mathrm{m}} = \mathrm{P}_{1}^{\mathrm{m}} \prod_{\mathrm{i}=1}^{\mathrm{n}-1} \mathrm{I}_{\mathrm{i,i+1}}^{\mathrm{m}} \tag{2a}$$

$$W_{n}^{m} = \frac{R_{n}^{m}}{R_{1}^{m}} W_{1}^{m} \tag{2b}$$

$$W_{n}^{m*} = W_{n}^{m}(1 + \mathrm{S}_{\mathrm{n}}^{\mathrm{m}}) = W_{n}^{m}(1 + \mathrm{P}_{1}^{\mathrm{m}} \prod_{\mathrm{i}=1}^{\mathrm{n}-1} \mathrm{I}_{\mathrm{i,i+1}}^{\mathrm{m}}) = \frac{R_{n}^{m}}{R_{1}^{m}} W_{1}^{m}(1 + \mathrm{P}_{1}^{\mathrm{m}} \prod_{\mathrm{i}=1}^{\mathrm{n}-1} \mathrm{I}_{\mathrm{i,i+1}}^{\mathrm{m}}) \tag{2c}$$

3. Secondary Weight Improvements in Subsystem Groups:
   The overall savings and masses of the system group G – consisting of k subsystems – result from the single savings and masses as following.

$$\mathrm{S}_{\mathrm{G}}^{\mathrm{m}} = \mathrm{R}_{1}^{\mathrm{m}}\mathrm{P}_{1}^{\mathrm{m}} + \sum_{n=2}^{k} \mathrm{R}_{\mathrm{n}}^{\mathrm{m}}\mathrm{S}_{\mathrm{n}}^{\mathrm{m}} = P_{1}^{\mathrm{m}-1} \tag{3a}$$

$$W_{G}^{m*} = \frac{\mathrm{W}_{1}^{\mathrm{m}}}{\mathrm{R}_{1}^{\mathrm{m}}} \sum_{\mathrm{i}=1}^{\mathrm{k}} \mathrm{R}_{\mathrm{i}}^{\mathrm{m}} \cdot \left(1 + \mathrm{P}_{1}^{\mathrm{m}} \prod_{\mathrm{j}=2}^{\mathrm{i}} \mathrm{I}_{\mathrm{j-1,j}}^{\mathrm{m}} \right) \tag{3b}$$

4. Primary Weight Improvement on next prior Subsystem Group:
   These overall savings and adapted masses in system group G are equivalent to a primary measure in system group G on system level *m-1* Calculation steps 1 and 2 can be repeated.

$$\mathrm{S}_{\mathrm{G}}^{\mathrm{m}-1} = \mathrm{R}_{1}^{\mathrm{m}-1}\mathrm{S}_{\mathrm{G}}^{\mathrm{m}} + \sum_{n=2}^{k} \mathrm{R}_{\mathrm{n}}^{\mathrm{m}-1}\mathrm{S}_{\mathrm{n}}^{\mathrm{m}-1} \tag{4a}$$

$$W_{G}^{m-1*} = \frac{\mathrm{W}_{1}^{\mathrm{m}-1}}{\mathrm{R}_{1}^{\mathrm{m}-1}} \sum_{\mathrm{i}=1}^{\mathrm{k}} \mathrm{R}_{\mathrm{i}}^{\mathrm{m}-1} \cdot \left(1 + \mathrm{S}_{\mathrm{G}}^{\mathrm{m}} \prod_{\mathrm{j}=2}^{\mathrm{i}} \mathrm{I}_{\mathrm{j-1,j}}^{\mathrm{m}-1} \right) \tag{4b}$$

5. Secondary Weight Improvement on overall System:
   These calculation steps have to be executed until system level 0 is reached. For example the secondary weight improvement on highest system level is calculated.

$$\mathrm{S}^{0} = \mathrm{S}_{\mathrm{G}}^{1} = \mathrm{R}_{1}^{1}\mathrm{S}_{\mathrm{G}}^{2} + \sum_{n=2}^{k} \mathrm{R}_{\mathrm{n}}^{1}\mathrm{S}_{\mathrm{n}}^{1} \tag{5}$$

6. New Weight Ratios due to overall Weight Improvement:
   Based on step 4 all links in the system structure tree not regarded yet have to be in consideration (top-down) and the new weight ratios R_{n}^{m*} in all links can be calculated (W_{n}^{m-1*} for the weight of the superior subsystem which the other subsystems with weight W_{n}^{m*} are depending on).

$$R_{n}^{m*} = \frac{W_{n}^{m*}}{W_{n}^{m-1*}} \tag{6a}$$

$$T_{n}^{m*} = \frac{W_{n}^{m*}}{W_{o}^{*}} \tag{6b}$$

7. New Weight Determination of Subsystems due to Change of Weight Ratios:
   Based on the adapted weights due to the secondary weight improvements in the specific and regarded subsystems, the weights in the subsystems not considered yet can be determined.

$$W_{n}^{m*} = W_{n}^{m-1*} R_{n}^{m} \tag{7}$$

3.2.6 Calculation example

An example of a simply hierarchically decomposed system is given in Figure 4.

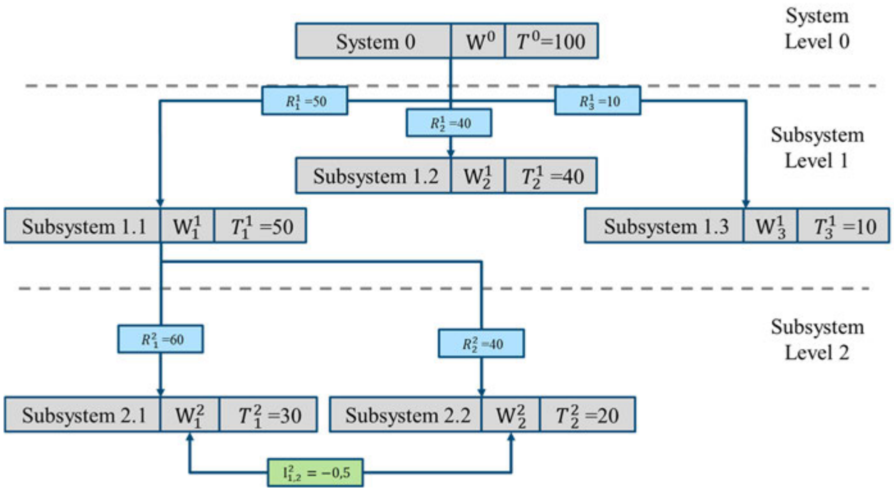

Figure 3. Example of decomposition with weight impact factors

The exemplary calculation procedure of the weight changes and thus the weight propagation in this simply and hierarchically decomposed system (cf. Figure 3) is a combined top-down / bottom-up process and follows these steps:

1. Application of a primary weight improvement (P_1^2) measure to *Subsystem 2.1* which results in a saved weight $\varDelta W_1^2$ (W_1^2: weight before, W_1^{2*}: weight after)

$$W_1^{2*} = W_1^2\,(1 + P_1^2) \tag{8a}$$

$$\varDelta W_1^2 = W_1^{2*} - W_1^2 = W_1^2(1 + P_1^2) - W_1^2 = W_1^2 P_1^2 \tag{8b}$$

2. Determination of secondary weight improvement (S_2^2) in subsystems on the same level (*Subsystem 2.2*) by using the weight impact ($I_{1,2}^2$) factor and the weight ratios to the superior subsystem (R_1^2, R_2^2).

$$S_2^2 = I_{1,2}^2 P_1^2 \tag{9a}$$

$$W_2^2 = \frac{R_2^2}{R_1^2} W_1^2 \tag{9b}$$

$$W_2^{2*} = W_2^2(1 + S_2^2) = \frac{R_2^2}{R_1^2} W_1^2\left(1 + I_{1,2}^2 P_1^2\right) \tag{9c}$$

$$\Delta W_2^2 = W_2^{2*} - W_2^2 = \frac{R_2^2}{R_1^2} W_1^2 I_{1,2}^2 P_1^2 \tag{9d}$$

3. The secondary weight improvement (S_1^1) is derived from weight ratios R_1^2 and R_2^2 as well as the weight improvements P_1^2 and S_2^2. The improved weight of subsystem on next higher system level (*Subsystem 1.1*) is the sum of the individual improved weight from the *Subsystems 2.1* and *2.2*.

$$S_1^1 = R_1^2 P_1^2 + R_2^2 S_2^2 = P_1^2(R_1^2 + I_{1,2}^2 R_2^2) \tag{10a}$$

$$W_1^1 = W_1^2 + W_2^2 = W_1^2\left(1 + \frac{R_2^2}{R_1^2}\right) \tag{10b}$$

$$W_1^{1*} = W_1^{2*} + W_2^{2*} = W_1^2\left(1 + P_1^2 + \frac{R_2^2}{R_1^2} + \frac{R_2^2}{R_1^2} I_{1,2}^2 P_1^2\right) \tag{10c}$$

$$\Delta W_1^1 = W_1^{1*} - W_1^1 = W_1^2 P_1^2 \left(1 + \frac{R_2^2}{R_1^2} I_{1,2}^2\right) \tag{10d}$$

4. The new weight ratios R_1^{2*} and R_2^{2*} relating to the superior *Subsystem 1.1* are determined

$$R_1^{2*} = \frac{W_1^{2*}}{W_1^{1*}} = \frac{1+P_1^2}{1+P_1^2+\frac{R_2^2}{R_1^2}+\frac{R_2^2}{R_1^2}I_{1,2}^2P_1^2} \tag{11a}$$

$$R_2^{2*} = \frac{W_2^{2*}}{W_1^{1*}} = \frac{\frac{R_2^2}{R_1^2}(1+I_{1,2}^2P_1^2)}{1+P_1^2+\frac{R_2^2}{R_1^2}+\frac{R_2^2}{R_1^2}I_{1,2}^2P_1^2} \tag{11b}$$

5. This procedure has to be repeated in every system level until total system weight improvement can be determined.

In Figure 4, there is an example for the calculation of secondary weight improvements in the considered system when improving weight (-10%) in *Subsystem 2.1* with primary measures (P_1^2). With this simple hierarchical decomposition and the formulas given above, it is relatively simple to calculate the weight improvement of the other subsystems and the system by application of secondary measures ($S_1^1$and S_2^2). 10% decrease of weight in *Subsystem 2.1* causes 5% weight increase in *Subsystem 2.2* with considering the weight impact index. Having these two weight changes the calculation of the weight change of *Subsystem 1.1* results in 4% weight decrease. The new weight ratios in system level 2 are changing to R_1^{2*}=*56.25%* and R_2^{2*}=*43.75%*. The weight improvement in system level 0 comes with R_1^1 to 2% weight decrease. Concerning that there is no horizontal connection between the subsystems in level 1 and with the weight ratios given, the weight of the *subsystems 1.2* and *1.3* can be re-defined starting at the system as a whole.

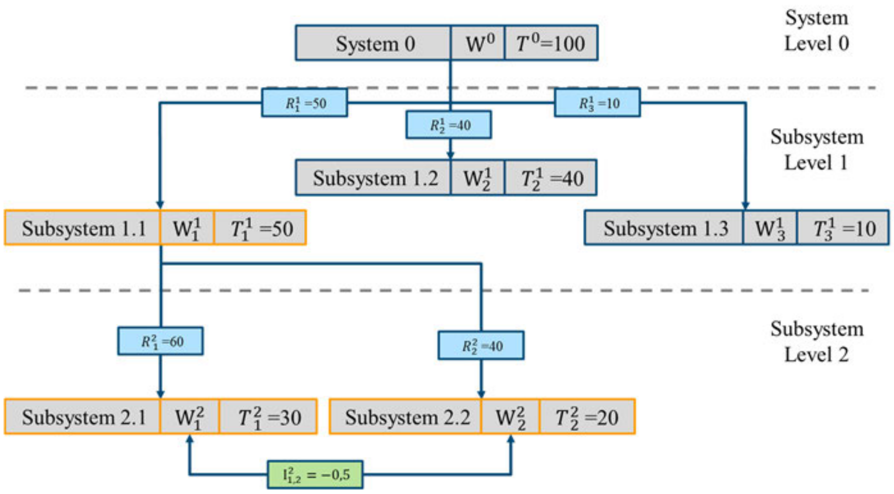

Figure 4. Example of weight propagation by application of primary (P_1^2) and secondary weight improvement (S_1^1 and S_2^2)

4. Conclusion and outlook

Secondary weight improvements amend traditional lightweight design and show great potentials when optimizing weight in a considered system. Systematically fostering secondary weight improvements is therefor an important methodical element of and prerequisite for weight optimization and, from a broader perspective, for sustainable product engineering.

However, the identification and determination of these secondary weight optimizations are the core issue. In this contribution, a calculation and identification method is proposed within a process model for the development of weight-optimized mechatronic systems. The identification results from the knowledge of interdependencies between subsystems which can be represented by the introduction of weight impact factors. The calculation of the secondary weight improvements is limited here to systems with a simply hierarchical structure and must be obviously extended to more complex system structures. Moreover, the calculation is only considering the system decomposition process from given function structures. But it should be possible to determine or at least identify secondary weight optimization potentials of function structures which is subject of further research.

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