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Sustainable Aspects Regarding a Multi-Criteria & Cross-Component Prediction of Property Change Potentials Within the Pre-Development Phase of Technical Product Systems

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Abstract

A required faster generating of concepts due to a significantly shorter pre-development time in the automotive industry without physical prototypes is a key factor to reach a higher product maturity more readily and quickly, especially in terms of reducing development costs but also environmental impacts. Therefore, and with regard to a more agile development process, tailored product property changes have to be considered right at the beginning.
Concerning this matter, the contribution presents a multi-criteria and cross-component systemic and systematic matrix-based analysis process of property change potentials within the pre-development phase of technical products. Herein, and based on the development of weight-optimized systems, a continuous monitoring and tracking of certain modifications of diverse sustainability factors (social and environmental) can be easily made and partly be directly influenced by a corresponding redesign of relevant and hierarchically ordered components.

Keywords: Design for X (DfX); Secondary Lightweight Design; Multi-Dimensional Optimization; Property Change Propagation; Sustainability

1. Introduction and Motivation

Nowadays new product developments often pursue different goals. In this way, for example, an adequate technical performance capability along with a concomitant resource efficiency (material but also energy) is playing an ever-

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increasing role in the development of advanced systems within almost all engineering sectors, particularly in the tremendously cost-driven automotive industry. Thus, concerning the latter, additionally increased environmental regulations (e.g. the target value of 95 g/km of CO_2 for 2020 of the EU CO_2 emission standards for passenger cars [1]) are focused most keenly across the whole product lifecycle (PLC), primarily related to the regulatory restrictions and economic penalties, on the one hand, as well as due to the continuously rising (customer) awareness of sustainable aspects, on the other hand. In consequence, it is inevitable for a prospective agile development, and with it a micro-iteration-based change management process to apply a holistic system consideration in context with appropriate product property changes already within the pre-development phase of technical products. Subsequently, a demanded quicker generating of concepts without physical or even less virtual prototypes can be realized, which, in the end, can lead to a significant shortening of the pre-development time, and thus to a sharper increase of product maturity.
Concerning this matter, and with regard to the former originated secondary weight propagation (secondary lightweight design) [2, 3], the contribution presents an extended framework of a multi-criteria and cross-component systemic and systematic matrix-based analysis process of property change potentials [4] within the pre-development phase of technical products. Herein, apart from the development of weight-optimized and cost-effective systems, a continuous monitoring and tracking of certain modifications of diverse sustainability factors (social and environmental) can be easily made and partly be directly influenced by a corresponding redesign of relevant and hierarchically ordered components. Accordingly, and followed by a previous recapitulation (section 2) of appropriate state-of-the-art approaches regarding a holistic consideration of lightweight design along with cost and sustainability aspects as well as a general change propagation of product properties and a matrix-based system modelling, section 3 predefines the fundamental framework of the matrix-based system modelling to predict property change propagations based on secondary weight improvements. Finally, section 4 extends the scope of the multi-criteria system model approach to more sustainable aspects by highlighting a synoptically basic value. By giving a discussion and outlook in the end (section 5), the presented approach is critically being reviewed.

2. State of the Art

2.1. Lightweight Design – Economic and Ecological Interdependencies

Weight savings in technical products are becoming more and more important, especially regarding efficiency aspects, and ultimately initiate new challenges for companies at the same time. Therefore, lightweight design is considered as one key part to sustainable products, mainly in areas of mobility [5]. In this context, however, the product development often deals with highly heterogeneous targets, as innovative lightweight design (e.g. strategies like constructive, material or process-specific measures, and/or diverse constructive techniques such as differentiated, integrated, hybrid or multi-material design) has to be combined with economic and ecological advantages throughout the entire product life cycle (PLC), see [6]. Accordingly, among others [7, 8], some studies already exist which combine cost and environmental aspects within the framework of lightweight engineering by using different calculation and assessment methods (e.g. analysis of environmental impacts by Ashby's material indices or eco-indicator).

Thus, for instance, Ungureanu et al. [9] developed a sustainable model, which quantifies costs and environmental impacts by means of a body-in-white (BIW) structure in conventional steel (25% recycled) and lighter mass equivalent aluminum via the four major stages of the life cycle "pre-manufacturing" (i.e. material processing), "manufacturing", "use" and "post-use", by maintaining the same vehicle design and using the (almost) same manufacturing processes for body components. In the end, and based on the amount of costs and environmental impacts focused on the CO_2-emissions, this study proves the overall benefit of using lighter materials such as aluminum (75% recycled) in automobile body structures with respect to environment and economy (as well as society, manufacturability, functionality and recyclability/re-manufacturability [10]) since a break-even point of one year or about 23,000 km (14,250 miles) (emissions) or rather three years (costs).

Witik et al. [11], however, calculates the costs and environmental impacts of various lightweight composite structures over the entire life cycle and compares them with those of magnesium and steel. For this purpose, a thin (rectangular) steel profile is replaced by the lighter materials in an application of the automotive industry. Due to the commonly longer production cycles and higher material costs, the considered lightweight materials are more