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Function-based benchmarking to identify competitor-based lightweight design potentials

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Abstract

The development of lightweight design solutions can have many reasons. Examples are resource efficiency (e.g. automotive industry, aerospace industry), the reduction of accelerated mass (e.g. transport) or comfort reasons (e.g. hand-held devices). The weight of a product is defined essentially in the early phase of product development. In the subsequent development phases, comparatively only minor weight savings can be achieved. Therefore, the integration of lightweight design methods into the early phase is advisable.
One possibility of supporting the product developer in the early design phase is the use of benchmarking. However, product benchmarking is often based on components. The abstract description of a product as a whole of its functions offers the possibility of detachment from existing component structures. This strategy is subject to the Extended Target Weighing Approach (ETWA), which represents a function-based lightweight design method. After identifying functions that are associated with too high mass, costs and CO2 emissions, they are methodically transferred into new concept ideas that are lighter, cheaper and more ecological.
The contribution discusses an adaption of the ETWA in order to identify competitor-based lightweight design potentials and to support the generation of concept ideas. Therefore, the existing ETWA is modified in order to be able to compare previously defined competitor products at functional level with the own product. Assuming that the benchmark product fulfils the same functions under the same requirements, a function portfolio, which is necessary for the ETWA, can be used to quickly classify the own product in competition and to derive competitor-based lightweight design potentials. However, this procedure needs to be adapted if the benchmark product fulfils functional requirements better or worse than the own product. The paper describes how the function portfolio can be systematically expanded to be able to make early assessments of the product's lightweight design potential.

Keywords: benchmarking; design method; lightweight design; cross-component design;

1. Introduction

The challenges in modern vehicle construction are aimed at achieving high functionality and the associated customer benefits. In this context, the aspects of resource conservation and the effects on global environmental criteria should always be taken into account. In order to achieve the environmental criteria, the use of lightweight design plays a major role. However, the times when lightweight design was used at any cost are over. Nowadays, the targeted use of lightweight design activities plays a decisive role.

The chosen product concept or design already sets 80 percent of the weight of the final product [1]. In the early phase of product development, in which the concept is determined, there is a high degree of freedom in design. Thus, the application of lightweight design methods in the early phase is attractive. However, design freedom also leads to a high degree of complexity in this phase. This is why the product developer should be supported by methods that stimulate creativity when generating new design concepts. In the following, this contribution presents a method for the identification of competitor-based lightweight design potentials through function-based benchmarking.

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2. State of the Art

2.1. PGE – Product Generation Engineering

The model of PGE – Product Generation Engineering according to ALBERS et al. [2] is a description model for the development of mechatronic systems. It is an empirically founded approach that enables the research and development of new methods and processes for the planning and control of product development processes. The description model of product generation development integrates previously fragmented approaches of classical design methodology [3] and innovation management [4]. Consequently, the basis for the development of new products is always formed by a reference system. The elements of this reference system, are adopted by the following development activities: Embodiment Variation (EV) and Principal Variation (PV) as well as Carry-over Variation (CV) [2]. The targeted adoption and new development of technical subsystems therefore characterizes a new product generation. The model of PGE enables a qualitative and quantitative planning, classification and description, and therefore the management of a product development task. Particular importance is attached to the early phase in the model of PGE when estimating and assessing the effects of decisions made within the framework of the product specification [5]. Starting with the initiation of a project, the essential elements of the initial target system [6] are derived in this phase in the development process of a new product generation. The essential starting point of the early phase during working on concepts is information on elements of the reference system as well as their acquisition and new development shares. The systematic application of a reference system not only reduces the development risk, but also exploits the potential for saving resources [5].

2.2. Benchmarking

Benchmarking is one of the most effective methods to make external knowledge available to your company, department, development team or yourself. In literature, there are many numerous definitions for benchmarking. A widely used and often-quoted definition comes from CAMP [7]. It states that benchmarking is the search for the best industry practices, whose implementation leads to superior performance. However, once promising best industry practices have been identified, they need to be adapted for individual application [8].

Benchmarking can be classified in various ways [9]. One possible classification is to subdivide according to *content* and *type* of benchmarking [10].

For the content, different evaluation criteria can be used depending on the object of the benchmarking (product, process, organization and strategy benchmarking) [11]. Evaluation criteria can be qualitative or quantitative for example function, customer benefit & quality (durability, accuracy), resource expenditure (material consumption, energy consumption), costs (Process costs, cost price) or time specifications (Time to Market, delivery time, repair time) [11].

For a successful benchmarking, the type of benchmarking and thus the selection of the right reference objects is decisive [12]. In this context, a distinction can be made between benchmarking partners. Depending on the proximity of these benchmarking partners to the own company with regard to the branch and organization, new opportunities and challenges arise during the benchmarking process. Fig. 1 shows four basic types of benchmarking according to FAHRNI et al. [8].

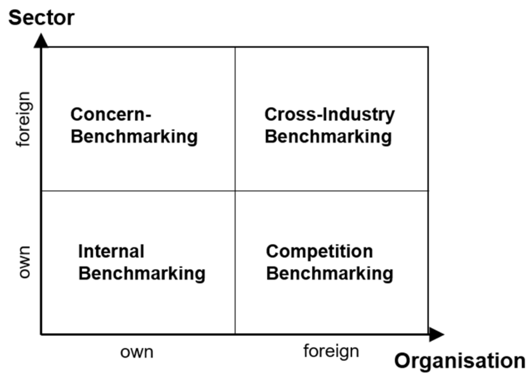

Fig. 1. Categories of benchmarking according to FAHRNI et al. [8]

Internal benchmarking provides very good access to data and therefore makes a comparison of key performance indicators very easy. However, the potential for new knowledge is rather low.

Concern benchmarking data is also easily accessible. However, transferability between the divisions of a company is only possible to a limited extent.

The best-in-class idea is central to *competition benchmarking*. This type of benchmarking offers a great potential and the direct competitor can always be monitored. Disadvantages are limited access to data and the legal framework that must be adhered to.

Cross-industry benchmarking offers the highest innovation potential through out-of-the-box thinking. However, it is enormously time-consuming to ensure transferability and to collect the appropriate data.

Therefore, benchmarking serves as a basis for measuring performance and generating ideas for improvement [13]. In this contribution, this idea is transferred to lightweight design and it is shown, how function-based product benchmarking can support the generation of concept ideas for new products.

2.3. Function-based product development

The successful development of products requires the customer to be integrated into the development process as early as possible [3, 14]. This can be done on the basis of an open solution formulation of the intended purpose of a technical system [14] the so-called functions. The technical function of a product can be subdivided into main, partial and secondary functions [3]. According to DENGER et al. [15], a transparent understanding of the link between the structure of a technical system and its functions requires a function-oriented and model-based formalisation in the product development process. Recent work shows the need for integrating function-based approaches into systems engineering in the context of the automotive industry [6].

Function-based approaches have also found their way into the specific context of lightweight design. One of the first contributions was published by FEYERABEND [16], who transferred the idea of value analysis to lightweight design. POSNER et al. [17] took this as a starting point and presented a method called function mass analysis. PONN and LINDEMANN [18] suggest a method called functional weight analysis that transfers the idea of target costing to mass.

ALBERS et al. [19] came up with the Target Weighing Approach (TWA) that abstracts the basic principles of value analysis and target costing and set them in the context of lightweight design. To be able to assess economic and ecological lightweight design solutions, the TWA has been extended [20]. The Extended Target Weighing Approach (ETWA) is based on the analysis of technical functions and the efforts (mass, costs, CO2 emissions) of a product. Based on that, within the Function-Effort-Matrix (see Fig. 2) the effort per function is determined by assigning the subsystems' contribution to the fulfillment of the functions.

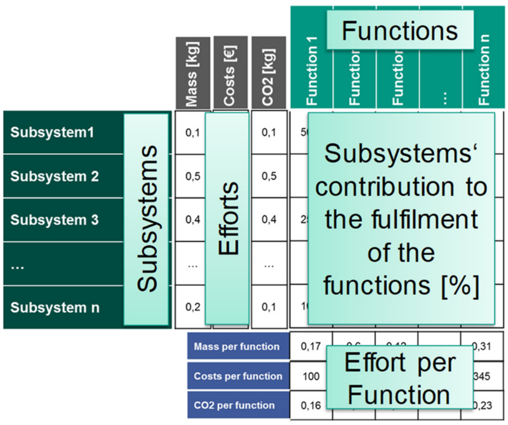

Fig. 2. Function-Effort-Matrix according to [21]

Together with the relative importance of each function, functions with a too high effort compared to their importance can be identified. In order to reduce the system weight, these functions should be transferred in new concept ideas. The workflow of the ETWA is shown in Fig. 3.

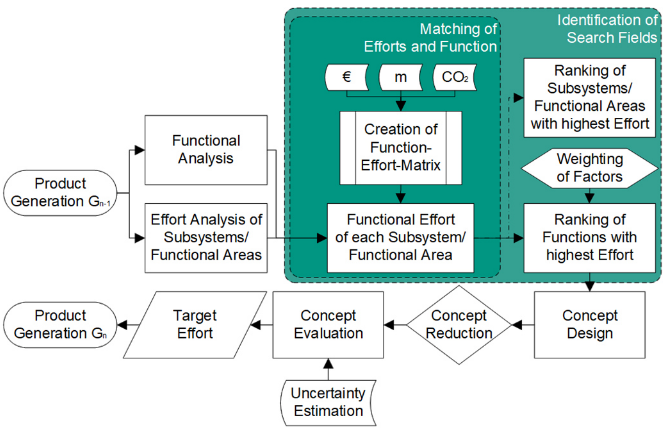

Fig. 3. Workflow of the ETWA according to [22]

3. Benchmarking within the ETWA

3.1. Selection of the benchmark scope

The selection of the benchmark product is of crucial importance and determines the support potential of the benchmark method. A benchmark product is a product to be compared to the own reference product and adds new knowledge elements to the reference system in the model of PGE. The relevant data for the benchmarking of external products can be obtained through the purchase, decomposition and subsequent analysis of the benchmark product. In order to minimize this effort, service providers have meanwhile specialized in collecting benchmark information. For example, the benchmarking platform A2Mac1 offers benchmark data particularly for companies in the automotive industry.

For this contribution, that means benchmarking in the automotive industry, the vehicles are divided into the respective segments according to the EU regulation. In this way, vehicles in their segment can be compared with competitors and the position of the own product in the market can be analyzed. In addition, a comparison with vehicles from other segments can show new technologies that have not yet been developed in the own segment. Similar to FAHRNI et al. [3], the reference products can thus be classified as shown in Fig. 4.

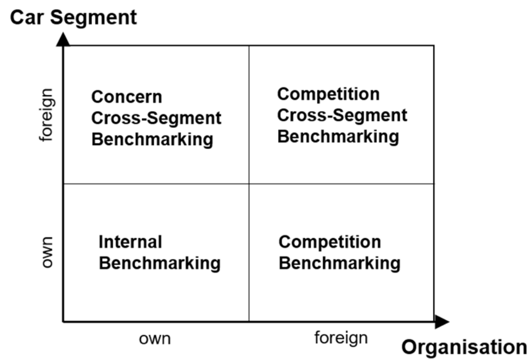

Fig. 4. Categories of benchmarking in the automotive industry

3.2. Benchmark method

The developed benchmark method is based on the Extended Target Weighing Approach. The aim of this method is to support the product developer in the generation of new concept ideas. In contrast to well-established component-based benchmark methods, the newly developed method relies on the function-based description of the products within the ETWA and the underlying functional masses, costs and CO2 emissions. On this functional level, the product developer receives information about lightweight design potentials that stimulate creativity for the generation of new concept ideas. Fig. 5 shows the workflow of the developed method.

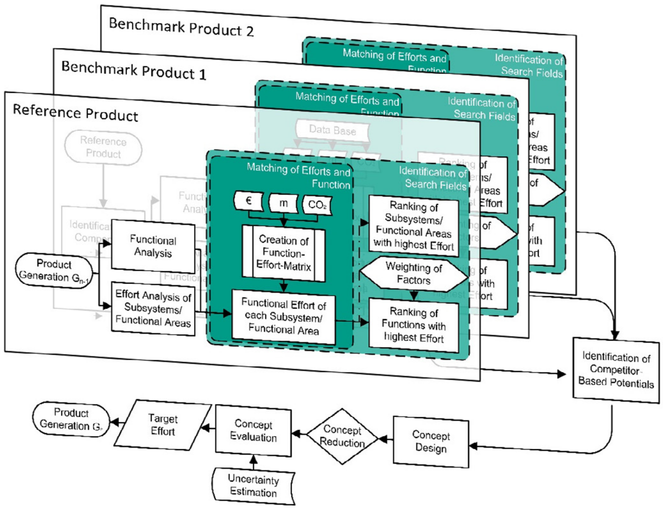

Fig. 5. Workflow of the benchmark method within the ETWA

The first layer (*Reference Product*) of the method describes the ETWA procedure for the own product, which is to be optimized in its mass, costs and CO2 emissions, as presented in the state of the art. The procedure is carried out up to the *Ranking of Functions with the highest Effort*. With the gained results, the function portfolio is created (see circles in Fig. 7).

Similarly, this procedure is carried out in a slightly modified version for the benchmark product. To introduce the procedure, the second layer (*Benchmark Product 1*) is shown separately in Fig. 6.

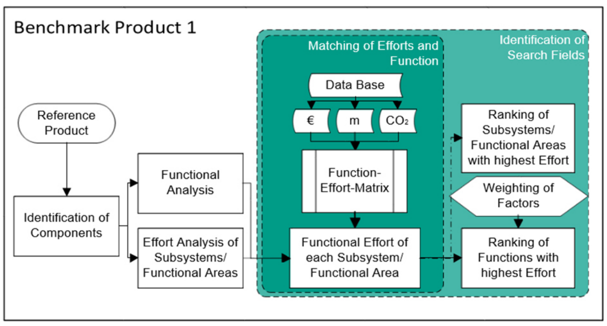

Fig. 6. Workflow for the benchmark product

First, a system boundary with the corresponding subsystems in the benchmark product must be identified, which cover the same system scope as the own product. In this context, it helps to question in which region the benchmark product fulfils the same functions as the internal reference product.

This is followed by a functional analysis of the previously defined components in the system boundary. Therefore, the functions of the own reference product provide a good starting point. These can be transferred to a large extent and it only has to be checked whether the benchmark product takes over further functions. If it is determined that the benchmark product does not fulfil a function of the own reference product, it must be checked whether the system boundary has possibly not been chosen correctly.

Additionally, the effort of the benchmark product has to be determined. This step is crucial, but at the same time difficult, as the competitor's data is usually not available or has to be estimated. For the mass data of the benchmark product, the benchmarking platform A2Mac1 can be helpful. For the costs and CO2 emissions the gathering of information is more difficult. Expert knowledge or calculation models can be used.

Expert knowledge or methodical support [23] is again helpful when filling out the Function-Effort-Matrix. The results for the benchmark product are also mass, cost and CO2 emissions per function.

Having gathered all the necessary information, the benchmarking of the different products starts. Therefore, the functions of each product can be applied with their effort over their relative importance in a function portfolio. The regression line is determined for the own reference product and included in the functional portfolio.

Assuming the same functions and their corresponding relative importance for both products leads to a function portfolio as generically shown in Fig. 7.

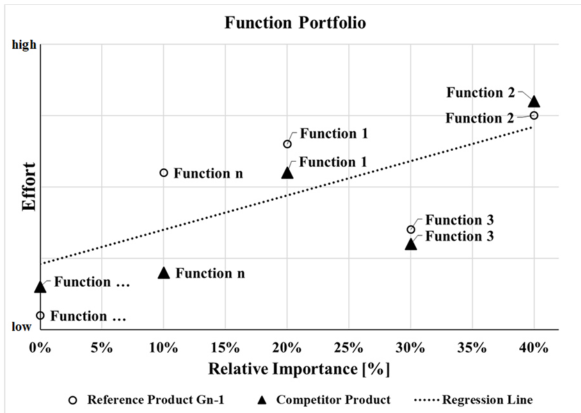

Fig. 7. Function portfolio for reference and benchmarking product assuming the same functions and relative importance

The assumption of the same functions and their associated relative importance based on the own reference product offers the possibility of a quick overview of the available lightweight design potentials, since the benchmark product does not have to be completely re-evaluated. In the car body construction of the automotive industry, this approach is also appropriate, as the functions performed by the car body are largely the same for all manufacturers on the market.

In Fig. 7, the circles represent the functional effort of the own reference product, while the triangles are the values of the benchmark product. Functions of the own reference product lying above the regression line still indicate lightweight design potential. If the functions of the benchmark product are below these functions with lightweight design potential on the y-axis, this shows competitor-based lightweight design potentials: the competitor is able to realize the functions better. Therefore, it is worth looking at the conceptual design of the benchmark product, as this could conceal optimization potential.

If different functions were identified in the functional analysis for the own reference product and the benchmark product, which are not due to an incorrect definition of the system boundary, the benchmark method can also be carried out. This automatically results in a different relative importance of the functions, which has to be taken into account during evaluation. Moreover, it should be checked why the functions are different. A different number of functions provides valuable input about the conceptual design of the benchmark product in terms of benchmarking. The competitor could have been able to take over more functions within the defined system boundary due to its conceptual design. If the competitor does not fulfil certain functions in the investigated system boundary, this also provides valuable information. The function may not be relevant at this point.

Comparing products from different manufacturers with each other can lead to another challenge. For example, there are two underbodies of battery electric vehicles to be compared. If the ranges of the vehicles differ from each other, this results in a different battery size and thus a different battery weight. As a result, requirements such as strength and stiffness of the load-bearing components differ. This would make a direct comparison of competing products impossible. In order to counter this challenge, a further axis has been added to the function portfolio. On this axis, the requirement for each function is specified. If a requirement for a function in the benchmark product now deviates from the own reference product, this will be respected in the evaluation. Fig. 8 shows the 3D function portfolio.

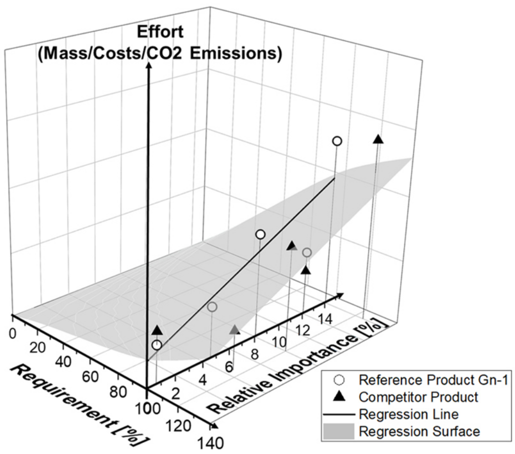

Fig. 8. 3D function portfolio with requirement axis

The own reference product is represented by 100% on the requirement axis. The regression line from the 2D function portfolio can also be found there. The three-dimensional representation results in a new regression surface. This surface is based on the assumption that a function which is fulfilled to 0% by its requirement must not cause any effort (i.e. mass, costs and CO2 emissions).

Finally, this 3D function portfolio allows the benchmarking of products that fulfil functions with different requirements.

4. Validation of the Approach

In order to validate the benchmark method introduced in section 3, a front rail of an automobile was investigated.

In the following it will be shown how the comparison of two competitors in the automotive sector with the help of the benchmark method reveals competitor-based lightweight design potential. Accordingly, a competition benchmarking (see Fig. 4) is carried out. These findings support the product developer in the creativity process for new concept ideas.

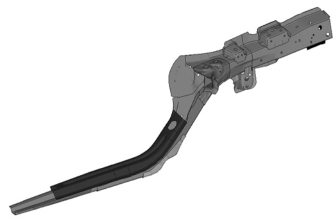

Fig. 9. Investigated rail [24]

An extract of the rail is shown in Fig. 9. For the purpose of better comprehensibility, a simplified scope of functions is considered for this contribution. The (reduced) functional analysis leads to functions such as *Enable assembly*, *Transmit and withstand subframe forces*, *Minimize front wall intrusion* or *Absorb (crash) energy*.

In addition to the functional analysis, an effort analysis is carried out to determine the mass, costs and CO2 emissions of all subsystems. Within the Function-Effort-Matrix, the subsystems' contribution to fulfillment of the functions is assigned and the corresponding mass, costs and CO2 emissions per function are calculated. Additionally, the product developer determines the relative importance of the considered functions by a paired comparison.

Having determined the effort and the Function-Effort-Matrix for the benchmark product, both data sets can be visualized in a function portfolio. In order to keep the example within this contribution comprehensible, a 2D function portfolio only for the mass (see Fig. 10) is used to explain the findings.

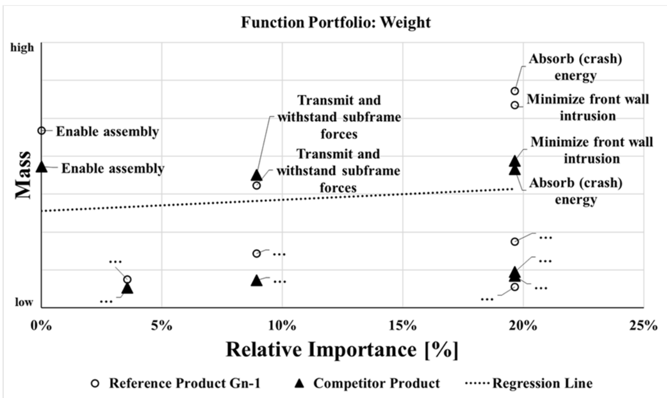

Fig. 10. 2D function portfolio for the mass of the reduced rail

As with the conventional ETWA, the regression line already provides an indication of those functions, which offer lightweight design potential. However, the comparison with the benchmark product can now provide concrete information. Fig. 10 shows considerable weight differences between the functions *Minimize front wall intrusion* and *Absorb (crash) energy* for the rail in this application example.

These functions have now been examined in more detail to find an answer explaining why the benchmark product is lighter. The mass drivers of these functions have been identified in the Function-Effort-Matrix of the own product. The components with the largest share in these functions and absolutely high mass are four parts in the curvature of the rail.

In the next step, these components are compared with the corresponding components in the competitive product. Differences in the used materials are detectable. While the own product uses high-strength steel with tensile strengths of approximately 1700 MPa, the competitor is able to use steels of about 700 MPa.

Reasons for this can be found in different design approaches and the chosen system boundary. For the own product, the identified components are stacked on top of each other and therefore are assembled horizontally. In the benchmark product, the affected components are divided and assembled vertically. This results in fewer components and smaller joining surfaces. In addition, a different connection to the underlying subframe can be identified. Possibly, an optimized force flow can be implemented in this way.

These findings can now be used to stimulate creativity in the *Concept Design* phase of the ETWA to generate new concept ideas.

5. Discussion and Conclusion

Benchmarking is used in many fields – including the field of automotive engineering. The demand for benchmark data is high, which is why service providers like A2Mac1 specialize in collecting mass data for benchmarking purposes. In the context of the model of PGE, this activity is a significant contribution in order to find elements of the reference system.

However, benchmarking is usually focused on component-by-component product analysis. The potential of changing the design remains often undiscovered.

In this contribution, the advantages of the function-based benchmarking approach in comparison to component-based approaches are shown. Only the interaction of several subsystems in a different design is significantly lighter in the competitor's product. When considering individual components in this example, only material differences can be determined. However, the reason for the reduced mass of the competitor lies in the different design.

Future work must demonstrate the transferability of the method to other system scopes. Moreover, it has already been determined that it is sometimes not sufficient to describe a function with just one requirement. Therefore, future investigations must show how several requirements per function can be considered. For this purpose, it would be conceivable to implement a weighted sum of the individual requirements.

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