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TOWARDS A SYSTEM MODEL TO IMPROVE THE QUALITY OF DECISIONS

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1. Introduction

Evaluation of components of complex technical systems faces two main problems: Firstly, the evaluation criteria often cannot directly be deduced from the overall development goals. Using wrong evaluation criteria reduces the quality of decisions. A methodology is needed, that shows a way to define them precisely. Secondly, the importance of the evaluation criteria is often hardly to determine. In all evaluation methods using weighted criteria (e.g. A. Breiing / R. Knosala [1], C. Zangemeister [2]), the importance is deduced from subjective estimations of participating experts. Despite of all methodological support to objectify the importances, in highly complex situations, where it is not possible for a human being to overview all relevant aspects, the quality of such estimations can be very low.

This paper introduces a new approach to determine the importance of evaluation criteria of system components more precisely. The approach bases on the relation between the importance value and the technical description of the product. As the question of importance is always linked to the definition of evaluation criteria, their representation in a system's description is discussed in the first part of this paper.

2. Background

This approach has been developed within a project about the system design engineering of a new elevator technology. The goal of the new elevator system is to increase the space exploitation. The chosen concept does not allow the further use of rope and counterweight, so that – as a consequence – all major components of the system have to be redesigned. Finally, the problem (as mentioned in the introduction) of deciding about component's solution variants appeared. Without support, it is not possible to overview the necessary information for reasonable decisions. The evaluation of the propulsion technology is very typical for such problems: Although the propulsion has a minor contribution to the development goals (reduction of lift area), it is one of the most important components on which many other components are depending. This example will be used to illustrate the theoretical approaches.

3. Evaluation criteria of subsystems

Evaluation criteria are to be deduced from the development goals (cf. Pahl/Beitz [4], Breiing/Knosala [1]). So the goals have to be discussed before considering the determination of evaluation criteria. In most of the cases, a new product is aiming at being more attractive to the customers as comparable products. So, development goals are related to customer's cognition. Thinking about an existing

product, the customer focuses on some attributes of the product – among all attributes that describe the product – that are relevant to him. Within this set of attributes, some are seen as deficient, so that the customer wants to have them improved. In such cases, the goal of the development is consequently the improvement of those deficient attributes. Attributes relevant to the customer may be as well more general as very precise (e.g. "safety", "shape of a button").

By following the proposition of V. Hubka [3], the set of product attribute terms perceived by the customer, resp. by the product's environment, must relate to the requirement criteria used for development. This means a first step towards the connection of development goals to the abstract description of a product. To determine the role of evaluation criteria within this description, it is useful to integrate the suggestion of A. Breiing in [6], to deduce the evaluation criteria directly from the list of requirements, since this list is corresponding to the definition of development goals. By combining these two propositions, it is possible to verbalize the first thesis:

Thesis 1:
Evaluation criteria of the overall product are equivalent to those attributes that
    a) *are perceived by the customer and are seen to be deficient,*
    b) *are sufficiently general to cover all solution variants.*

This thesis offers a clear link between the product description and the evaluation criteria. From the customer's point of view, technical solutions differ only in their attribute values. It is in the nature of engineering design, that the technical point of view is more precise. A technical solution description therefore uses more attributes. Thus, not only the attributes but also the relations between them are crucial to know for product design. In this paper, the entirety of all attributes and their relations is called "influence net". It usually contains cycles. The relations are directional and oriented towards the attributes perceived by the customers. An influence net is, finally, a way of describing a product based on technical information. It is the illustration of the knowledge of the effect of changing a technical parameter (attribute) on the customer's perception.

Each component of a product provides one part of the total influence net. With this illustration of a product, the evaluation criteria of a subsystem can be determined by

Thesis 2:
Evaluation criteria of a system's component are equivalent to those attributes that
    a) *feature an influence on the overall product's evaluation criteria,*
    b) *are sufficiently general to cover all component's solution variants.*

The connection between the component's attributes and the overall evaluation criteria are described within the influence net of the product. By knowing the overall evaluation criteria and one part of the technical influence structure, the second thesis facilitates the correct determination of the component's evaluation criteria. During the design process, the influence net will enhance and densify, so that further evaluation criteria may appear. With the influence net, the set of evaluation criteria can be well defined, which leads to a better quality of decisions.

To illustrate the consequences of the two theses, a part of the influence net of the elevator technology that is relevant to propulsion component is presented in figure 1. The black attributes are target attributes of the elevator system; the grey ones are the corresponding evaluation criteria of the propulsion component. The influence net between those attributes is complex and includes influence cycles. Thus, further attributes of other components (e.g. cabin structure, traffic concept) are involved. This demonstrates that evaluation criteria of one component always are depending on the influence net of other components. The manifold interrelationships including cycles do clearly contrast with the hierarchical structure of the evaluation tree ("Bewertungsbaum") proposed by C. Zangemeister [2]. This means that this proposal is not applicabable for the case studied in this paper.
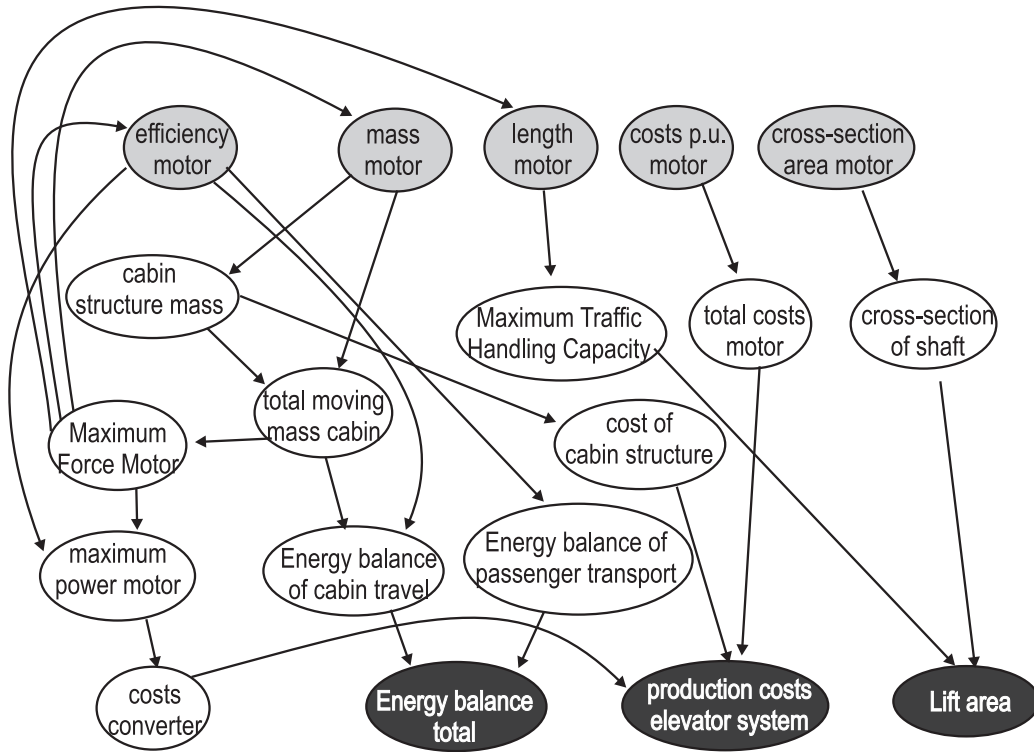
Figure 1. Section of the influence net of the elevator regarding the propulsion component

4. Importance of component's evaluation criteria

According to G.Pahl and W. Beitz, the goal of an evaluation is the determination of the value, resp. the benefit or the strength of one solution regarding the development goals [4]. Based on the influence net as a way of describing a product, this can be determined more precisely: The goal of a component's evaluation is to find the variant with the best effect on the improvable attributes (target attributes). As the variants differ only in their attribute values of the evaluation criteria, their effect on the goals is reflected in the changing of the target attribute values. This leads to a third thesis:

Thesis 3:
The importance of a component's evaluation criterion regarding one target attribute corresponds to the fraction of the changing of the component's evaluation attribute (ε_C) to the changing of the considered target attribute (ε_T) regarding a reference value in combination with an expected average changing of this value by the variants. This fraction is called "influence factor" (i_{C_T}).

$$i_{C\_T} = \frac{\varepsilon_T}{\varepsilon_C}$$

Assuming that the overall evaluation criteria are individually weighted (g), the total influence factor of a component's evaluation criterion regarding the development goals is equivalent to the sum of all influence factors multiplied with the target attribute's weight. ($i, j, m, n \in \aleph; g, i \in \Re$).

$$i_{Cj\_total} = \sum_{i=1}^{n} \left[g_i \cdot i_{Cj\_Ti} \right]$$

The overall importance (*im*) of an evaluation criteria is:

$$im_{Cj\_total} = \sum_{i=1}^{n} \left[g_i \cdot i_{Cj\_Ti} \right] \cdot \varepsilon_{Cj\_Average}$$

The consequence of this third thesis is that the importance of an evaluation criterion of a component can be determined by the influence structure of a product, meaning that there is no subjectivism anymore in finding the importance. The determination of importance is as exact as the technical knowledge about the product itself.

To illustrate the role of the influence net, it is again compared with the evaluation tree of C. Zangemeister [2]. Figure 1 shows, that the attribute "efficiency of the motor" is influencing the target attributes "energy balance" and "production costs of elevator system". Beyond the fact, that the net structure between the propulsion and the target attributes cannot be represented as hierarchy, the determination of the importance in the evaluation tree is based on subjective assumptions. In contrast to that, the importance based on the influence net relies on technical formulae and therefore is more precise. On the other hand, this means, that the application of this approach might be limited to component's evaluation.

5. Evaluation of component's variants

The importances based on thesis 3 can principally be included in known evaluation methods (e.g. C. Zangemeister [2], F. Kesselring [5], A. Breiing / R. Knosala [1]). The importance for those evaluation processes can be obtained by ranking the evaluation criteria with information from the influence net. But the result of such a proceeding is not correct in all cases. One problem results from influence cycles over the system borders of the component (e.g. the motor's mass is part of such a cycle, cf. figure 1). The effect of one variant on the other parts of the system leads to further changements of the variant's evaluation attributes. So the effect of a variant may be completely different in reality than estimated by this kind of evaluation. This means finally, that each variant possesses its own influence factors that take respect to additional influence cycles. To facilitate the determination of the variant's effect, a new evaluation method is proposed:

If one variant is set as reference variant (e.g. the ideal variant), all other variants are represented by the set of relative changings to the reference values of the evaluation attributes. By multiplying each changing factor (ε) with the individual influence factor (i) of the criterion (including all influence cycles), this results in the exact changing of the target attributes. So the best variant is the one with the most positive changing of the target attributes. With $j, m \in \aleph; \varepsilon, i \in \Re$, the changing of the target attributes due to variant V1 (ε_{V1}) is

$$\varepsilon_{V1} = \sum_{j} i_{Cj\_total_{V1}} \cdot \varepsilon_{Cj_{V1}} \; .$$

With this, it is possible to use directly the information from the influence net for evaluating component's variants, and considering all interrelations and cycles.

6. Products as a component of complex environments

If a product itself is a component of a superior system (e.g. the elevator is part of the building), the customer (e.g. investor) perceives the product through the filter of the superior system. The customer wants to invest in the superior system, and so, the attributes of the product relevant to him are depending on the interrelationships of the whole system.

In such cases of complex superordinate systems, the same difficulty as for component's decision appears: The customer is usually not able to weight directly the target attributes of the product, but the ones of the superior system. So the correct importances of the products evaluation criteria are hardly to be found. Furthermore, the effect of the new product depends on the interrelations with its environment. New influence cycles over the product's system border for example may provide a completely different effect on the aspects important to the customer.

As it usually is also possible to describe the superior system with attributes and interrelations, the concept of the influence net (thesis 1, 2 and 3) can also be used to determine the importance of the product's target attributes.

In figure 2, the application of this concept on the elevator technology is shown. For the customer (e.g. investor), one relevant attribute of the building is the return of investment. In this case, all elevator's target attributes do influence this relevant attribute of the building. With this measure, it is possible to do a balanced comparison of all technical and economical aspects.

Figure 2 is also showing a major influence cycle between the elevator system and the building: Reducing the lift area will increase the population of the building, which affects the target handling capacity of the elevator system. Finally, the real reduction of the lift area is smaller than only by analysing the lift system. It is crucial for correct decisions to integrate such interrelations in an evaluation.
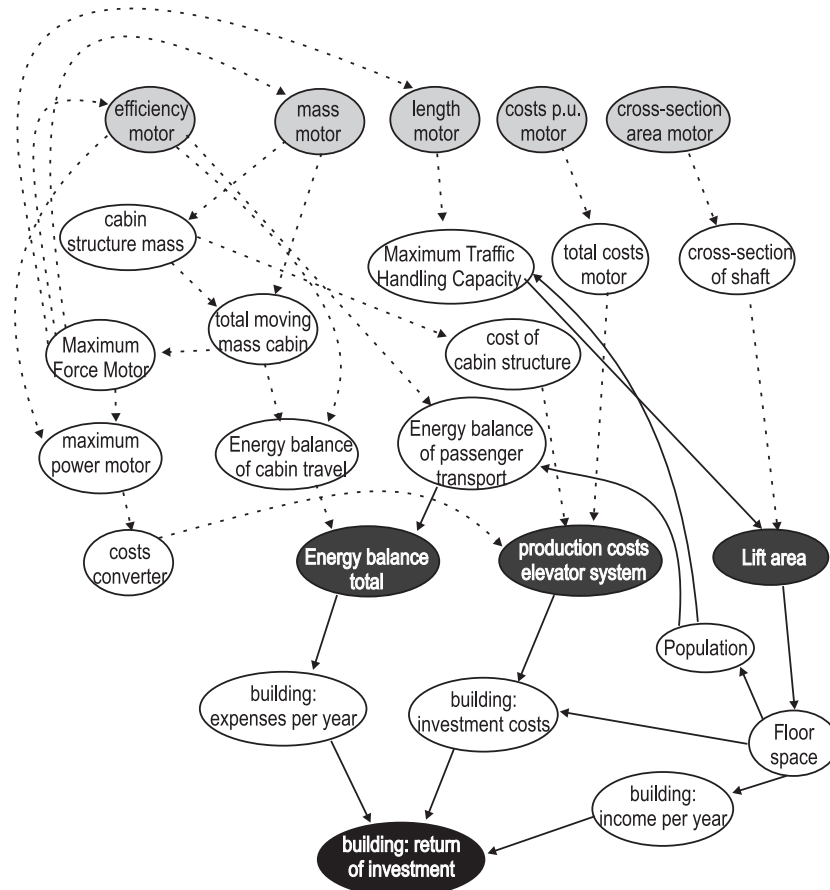

Figure 2. Combination of the influence structures of the building and the elevator system

7. Summary

For component's evaluation in complex systems it is hard to find both evaluation criteria and their importance. This paper introduces a new approach to support this kind of evaluation problem. Firstly, a concept of how the evaluation criteria are related to a specific technical description of the product, named "influence net", is shown. Based on this, it is possible to determine the evaluation criteria for component's evaluation by relying on the technical knowledge. This means, that even for components with little contact to the development goals, it is possible to find the correct evaluation criteria. In the second part, it is shown, how the importance of component's evaluation criteria is directly depending on the influence net and like this, on an exact model. This offers the exact determination of the importance also in highly complex systems. In the third part, a new approach of component's evaluation is presented, by which it is possible to integrate all kinds of interrelations, even influence

cycles. Finally it is shown, that the same approach can be used for products in complex environments in order to find all evaluation criteria and their importance.

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