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# OPERATIONALISATION OF THE VALUE ANALYSIS FOR DESIGN FOR LIGHTWEIGHT: THE FUNCTION MASS ANALYSIS

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## ABSTRACT

The mass has a great influence on the value of products from different industries. For example, by reducing the mass of a product, the energy consumption and CO2 emissions can be reduced. These influences, which the mass has on different product properties, show why lightweight design is becoming increasingly important.

Designers have to establish goals regarding mass in the early phases of the product development process, as otherwise the product may be too heavy after its design is completed. Nearly each function needs mass for its fulfillment but functions which are not important to the customer raise only the mass and not the customer value of the product. If designers had information about the importance of functions and the mass which is needed for their fulfillment, they would be able to discuss with their customer whether the functions are so important that they want to accept this extra mass in the product. Therefore, a method which supports designers in establishing goals regarding mass, and in analysing optimisation potentials, the importance of functions and the mass which is needed to fulfil the function based on the Value Analysis is operationalised in this paper.

*Keywords: design method, design for X, design for lightweight, value analysis*

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# 1 INTRODUCTION

The mass has a great influence on the value of products from different industries. By reducing the mass of a product, the energy consumption and $CO_2$ emissions can also be reduced. The dynamic properties of the product, such as the acceleration of cars, can be improved too (Ponn and Lindemann 2011). In the case of products which have to be moved or even carried by the user, the mass has an influence on the physical strain on the user. These influences which the mass has on different product properties show why a lightweight design is becoming increasingly important for different industries.
In order to realise a lightweight product, the mass has to be considered as an important factor in the early stages of the product development process. Ponn and Lindemann (2011) state that designers have to establish goals regarding mass in the early phases of the product development process, as otherwise the product may be too heavy after its design is completed. Establishing these aims in the early stages of the design process allows the designers to focus on reaching these goals regarding mass.
In literature on lightweight design, there are different lightweight strategies, for example conditional, manufacturing or material lightweight design (Henning and Moeller 2011), but there is no method which assists designers in analysing the mass optimisation potentials of products. This means, designers have no support in deciding which function or which assembly should be realised in a lighter way. They start their optimisation on randomly selected functions.
Nearly each function needs mass for its fulfillment, but functions which are not important to the customer raise only the mass and not the customer value of the product. Designers even have to decide which functions are realised without knowing the mass which is needed for fulfilling these functions. If designers had information about the importance of functions and the mass which is needed for their fulfillment, they would be able to discuss with their customer whether the functions are so important that they want to accept this extra mass in the product. Therefore, a method which supports designers in establishing goals regarding mass, and in analysing optimisation potentials, the importance of functions and the mass which is needed to fulfil the function is desired.

# 2 PROBLEM STATEMENT AND GOALS

Feyerabend (1990) has transferred Value Analysis (VA) for use relating to mass instead of costs. However, he does not operationalise this transfer with regard to developing mass goals in relation to the functions which have to be fulfilled and he does not analyse the importance of functions for the customer. Posner (2012) has analysed the approaches of VA and Feyerabend and has presented a framework for a method for developing mass goals and analysing optimisation potentials, the importance of functions and the mass which is needed for function fulfillment based on these approaches, but he did not operationalise this in detail.
Therefore, in the state of the art, there is no detailed operationalisation of such a method. The paper will operationalise the following hypothesis in order to answer the research question: *VA can be transferred for use with regard to mass as proposed by Feyerabend (1990) and thus the framework of Posner (2012) and a practical procedure for mass optimisation projects can be operationalised. This operationalised method supports designers in developing mass goals and analysing optimisation potentials, functions and the mass which is needed for fulfilling these functions*.

*Table 1. Overview of the research questions of the article*

| **Research Questions** | **Section** | |
|---|---|---|
| | **4** | **5** |
| What are the methods for developing mass aims and analysing functions and mass optimisation potentials? | | |
| How can VA be operationalised for developing mass aims and analysing functions, the mass which is needed for function fulfillment and mass optimisation potentials? | | |

In the first sections, the importance of considering functions and the importance of knowledge about the mass which is needed for the implementation of certain functions is discussed. In Section 3, the research method which is used to obtain the results of this paper is introduced. The research questions are shown in Table 1. These questions are answered in Sections 4 and 5. The operationalisation of the transferred Value Analysis is presented in Section 5. Also in Section 5, the most important steps of the proposed method are applied on a simple example in order to build up a better understanding of how the method works. In the discussion in Section 6, the innovation potential, the limitations and the further development steps of the method are described.

# 3 METHOD

The research presented is based on the Design Research Methodology (DRM) according to Blessing and Chakrabarti (2009). The research addresses three of four steps of the DRM. In the first step, the Research Clarification, the tasks are clarified and the research questions and hypothesis are developed (Sections 1 and 2). The results of the second step, Descriptive Study 1, are presented in the section on the state of the art (Section 4) and the results of the third step, the Prescriptive Study, are presented in Sections 5 and 6. The fourth step of the DRM, Descriptive Study 2, would be the extensive evaluation of the contents of this paper in order to comply with scientific requirements and the requirements of business practice.

The example given in Section 5, which is shown in order to aid understanding of the method, was worked through in a team of three mechanical engineers with a scientific background. As it is not a project which has been worked through in a team in the framework of an industrial project, it is only a support evaluation according to Blessing and Chakrabarti (2009) which helps to understand some background and which demonstrates the applicability of the method. Because it is not an extensive evaluation, this must be the next stage in the development.

# 4 STATE OF THE ART

In addition to the different lightweight design strategies, for example material or manufacturing lightweight design (Henning and Moeller 2011), literature on lightweight design provides the general methodical product development process according to Pahl et al. (2007) and others. However, there is no specific lightweight product development process. Also, in lightweight design, a lot of calculation methods, tools and software is available for supporting designers in optimising structures of product parts (Bendsøe and Sigmund 2004). In addition, Feyerabend (1990) presents the approach of transferring VA from its application in terms of costs to application with regard to mass in order to reduce the mass of existing products by means of lightweight design projects. Originally, VA was a method for design focusing on cost (DIN 2002). The aim of VA is to increase the value of an object. In VA, value is defined as the fulfillment of customer needs, e.g. the fulfillment of functions, divided by the resources used (VDI 2010). Moreover, the core idea of VA is for an interdisciplinary team to work together, which allows for a holistic view of the problem (Kermode 2000). Broderick (1992) added a trade-off factor to the definition of value which is defined as cost per kilogram and multiplied by product weight. Thus the weight of the product is indirectly taken into account. Posner (2012) develops the requirements which a method for design with regard to function and mass has to fulfill. Based on these requirements, he assesses different approaches, for example those of Feyerabend (1990) and Broderick (1992), and shows that there is a gap in design methodology and that VA could be useful as a basis for further development of a method for design with regard to function and mass and for developing mass goals. He also develops a framework for such a method called Function Mass Analysis (FMA). The approach of Feyerabend (1990) is based on an old version of VA. Feyerabend (1990) does not operationalise the development of mass goals and the analysis of optimisation potentials with consideration given to functions.

# 5 FUNCTION MASS ANALYSIS

In this section, FMA according to Posner (2012), as shown in Figure 1, is operationalised by transferring each step of VA (VDI 2010). In order to realise this, each step of VA will be discussed in the following subsections and transferred to application in terms of mass rather than costs. The approach is shown on a technical example, an air pump, with low complexity in order to aid easy understanding of the method.

## 5.1 Preparation, definition and planning of the project

The first steps of preparing, defining and planning a project can be similar to the procedure of VA according to VDI (2010). In the first step of FMA, the project has to be prepared. It needs to be clarified whether the problem can be solved by means of FMA. The project has to be defined in order to realise a proper project and proper results. In the stage of project planning, the working group has to be formed, a time schedule has to be drawn up and the infrastructure for team communication and meetings has to be established. After that, the work with regard to contents can be started. (VDI 2010)

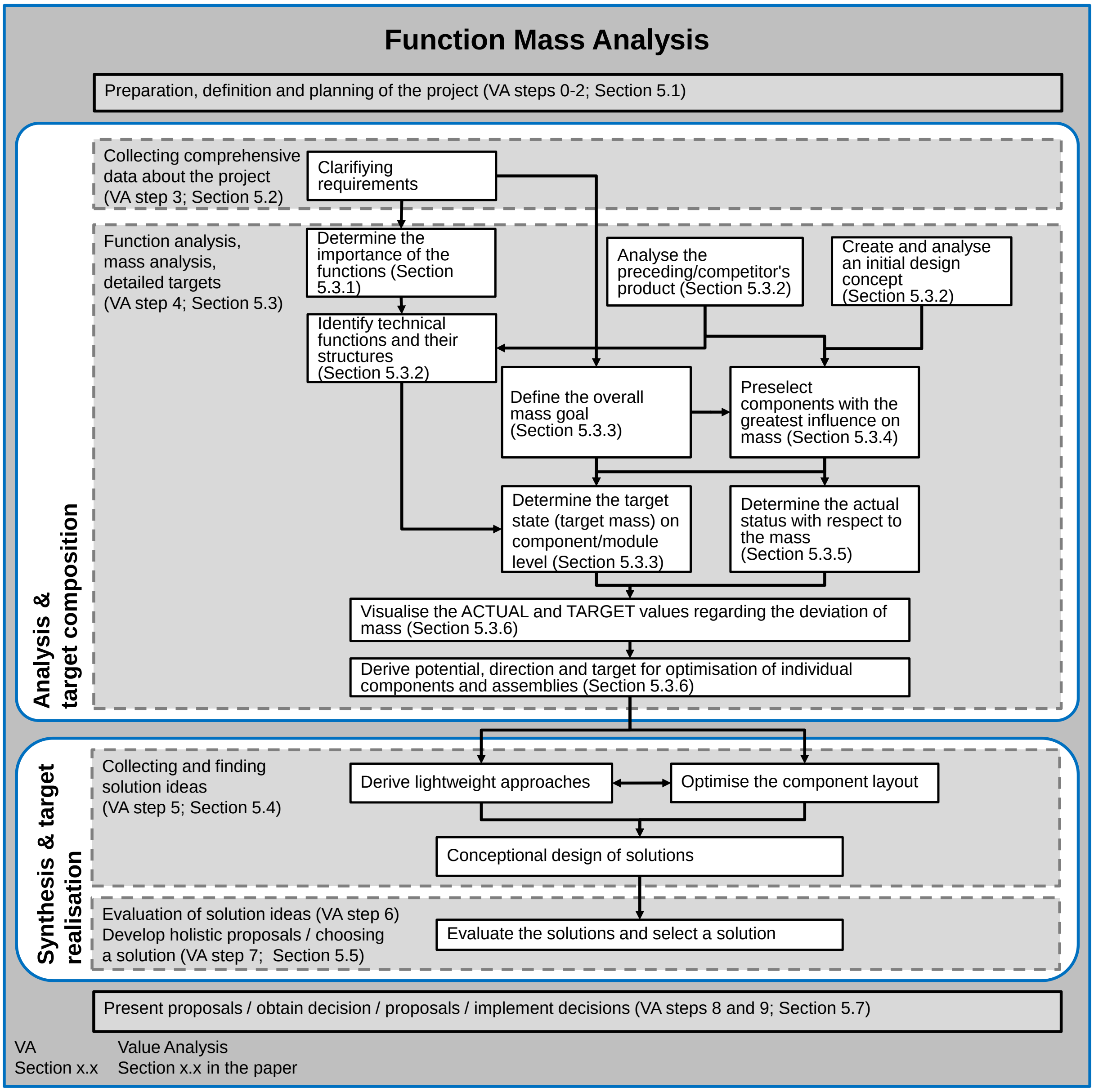


*Figure 1. Procedure for Function Mass Analysis (in accordance with Posner 2012)*

## 5.2 Collecting comprehensive data about the project

In this step, data about the competitors, the state of the art of the product and the competitors' products have to be clarified (VDI 2010). The total mass, the distribution of mass, the functions and the function structures of the competitors'or preceding products have to be analysed. For that purpose, the function structure according to Pahl et al. (2007) can be used. The advantage of this function structure compared with a FAST diagram (VDI 2010), which is one of the proposed methods of VA, is that the function structure supports the better completeness of the structure. Also in this step, benchmarking of the mass of competitors' products has to be carried out in order to develop an overall mass goal.

Furthermore, the requirements which have to be fulfiled by the product must be discussed and clarified with the customer. From the point of view of lightweight design, wishes which do not have to be fulfilled must be identified and requirements have to be questioned critically to ascertain whether they really have to be that strict.

As an example, a commercial air pump with two cylinders is considered in the following, as shown in Figure 2. Based on the analysis of this pump, the aim of our example project is to design a pump which can be used in a portable manner. This means that the customer can attach it to a bike and take it with him. For such use, the weight shall be reduced by 40 % compared with that of the pump for stationary use, shown in Figure 2. Also, some examples of customer functions and requirements are identified. These are "pumping air", "little manpower needed", "short pumping period" and "showing pressure". In the Value Analysis there is no strict distinction of the customer functions and requirements. Thus, in the following there is also no strict distinction, even though there are differences between the definitions of these two terms.

*Figure 2. Example of an air pump*

## 5.3 Function analysis, mass analysis, detailed targets

This is the most important step for our objectives of transferring the VA approach. In this step there are the largest number of differences between using the VA for costs or for lightweight design. For this reason, this step and its sub-steps have to be analysed in more detail.

### *5.3.1 Meeting customer needs and determining the importance of functions*

The aim of the product is to fulfill the needs of the customer. These needs shall be fulfilled by the functions of the product. The customer-oriented functions, as they are called in VA (VDI 2010), have to be clarified by interviewing the customer. Each function has a different level of importance for the customer. This means that the functions have to be weighted. As a methodical aid for this weighting, the "comparison of pairs" (Pahl et al. 2007) can be used to obtain a more objective result, as shown in Table 2 (VDI 2010). The function importance weight is the normalised factor which provides the information on the importance of the customer-oriented function.

*Table 2. Comparison of pairs*

| | Pumping air | Little manpower needed | Short pumping period | Showing pressure | **Total** | **Function importance weight** |
|---|---|---|---|---|---|---|
| Pumping air | 1 | 2 | 2 | 2 | **7** | **7/16=0.44** |
| Little manpower needed | 0 | 1 | 1 | 2 | **4** | **4/16=0.25** |
| Short pumping period | 0 | 1 | 1 | 2 | **4** | **4/16=0.25** |
| Showing pressure | 0 | 0 | 0 | 1 | **1** | **1/16=0.06** |

### *5.3.2 Analysis of technical functions of preceding or competitors' products*

If there are preceding or competitors' products, the technical functions of these products can be analysed. This can be done by establishing a function structure according to Pahl et al. (2007). If there are no related products, a new function structure for an initial design concept needs to be developed.
For the example under consideration, this means that the function structure of the competitor's pump has to be analysed and illustrated in this step, as shown in Figure 3.

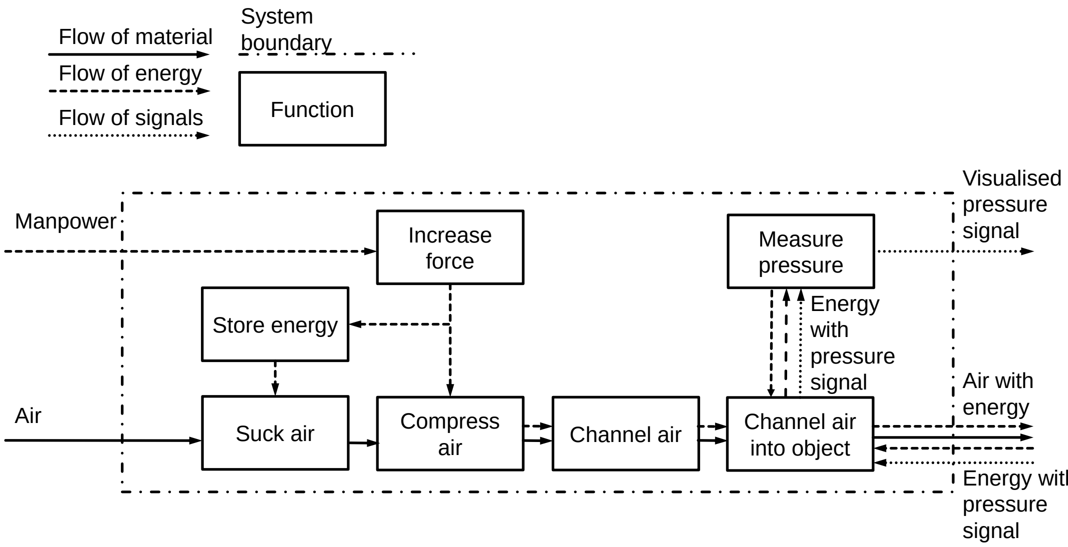


*Figure 3. Function structure of a competitor's air pump*

### *5.3.3 Correlation between customer-oriented and technical functions and development of function mass aims*

In order to analyse which technical functions fulfil the customer-oriented functions, a modified version of Quality Function Deployment (QFD) can be used. This guarantees the fulfillment of the customer-oriented functions and thereby ensures the focus on customer needs.

In Table 3, the technical functions have been listed on the first rows of the table and the customer-oriented functions in the left-hand column. The project team members determine the degree to which each technical function contributes to fufilling the individual customer-oriented function. It is given in percent and sums up to 100 %. Multiplying this factor in percentage with the function importance weight and summing this up for each customer-oriented function results in a factor which provides the information about the importance of each technical function.

*Table 3. Correlation between customer-oriented and technical functions*

| | | | Technical functions | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Function importance weight | Increase force | Store energy | Compress air | Suck air | Channel air | Channel air into object | Measure pressure |
| Customer functions | Pumping air | 0.44 | | | 45 % | 45 % | | 10 % | |
| | Little manpower needed | 0.25 | 70 % | 30 % | | | | | |
| | Short pumping period | 0.25 | 30 % | | 30 % | 30 % | 10 % | | |
| | Showing pressure | 0.06 | | | | | | | 100 % |
| | **Function importance weight** | | **0.25** | **0.08** | **0.27** | **0.27** | **0.03** | **0.04** | **0.06** |
| | **Function mass aim [in g]** | **805** | **201** | **61** | **219** | **219** | **20** | **35** | **50** |

In this case of the air pump, the mass of the new air pump should be 40 % below the mass of the competitor's product under consideration. Reducing the mass of 1341 g of the competitor's product by 40 % means that the total mass aim for the new product is 805 g. By multiplying the total mass aim by the function importance weight, the designers arrive at the function mass aim. How this aim can be interpreted will be presented in Section 5.3.6.

#### *5.3.4 Preselection*

If this method is used for a very complex product, parts can be preselected in order to minimise efforts. For this purpose, the “ABC method” according to Pahl et al. (2007) can be used. A possible problem of this preselection is that not all parts were considered and this can corrupt the results in some cases. The level of detail of the analysis can also be adapted by considering assemblies instead of parts. By doing so, the problem of not considering all parts can be avoided.
As the example of the air pump is a very simple one, there is no need for any preselection of parts.

#### *5.3.5 Weighing and correlation between parts, assemblies and technical functions*

In this step, the mass of the parts of the competitor’s or preceding product has to be determined. These parts contribute to the fulfillment of the functions of the product. The project team members have to estimate which part contributes which percentage to the fulfillment of which function (see Table 4).
By linking the parts to the functions, the mass of the parts can also be linked to the functions. Each function is hereby connected to a mass which is included in the product to realise the function fulfillment. As a consequence, the project team members know which mass is needed in the existing solution to realise the function.
Table 4 shows this process used for the example under consideration. In the first column the parts of the product are listed and in the second column the mass of the parts are listed. The second row shows the technical functions of the product. The project team members determine the degree to which each component contributes to fulfilling the individual technical function. It is given in percent and sums up to 100 % per row. Multiplying this factor by the weight of the part and summing this up for each part results in the function mass, as shown in Table 4. This means that the considered function needs this function mass for its fulfillment in the product being considered. How to use this result for demonstrating optimisation potentials is shown in the following sections.

*Table 4. Mass analysis*

| | | | Technical functions | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mass [in g] | Increase force | Store energy | Compress air | Suck air | Channel air | Channel air into tyre | Measure pressure |
| Parts | Hose | 60 | | | | | 100 % | | |
| | Pump cylinder | 409 | | | 50 % | 50 % | | | |
| | Base | 227 | 60 % | 40 % | | | | | |
| | Connector | 30 | | | | | 50 % | | 50 % |
| | Lever pedal | 372 | 60 % | 40 % | | | | | |
| | Pressure gauge | 31 | | | | | | | 100 % |
| | Cylinder base axis | 115 | 60 % | 40 % | | | | | |
| | Cylinder header axis | 37 | 60 % | 40 % | | | | | |
| | Spring | 33 | | 100 % | | | | | |
| | Adapter | 27 | | | | | | 100 % | |
| | **Function mass [in g]** | **1341** | **451** | **332** | **205** | **205** | **75** | **27** | **46** |

#### *5.3.6 Identification of optimisation potentials and deriving an optimisation ranking*

The function mass aims were calculated in Section 5.3.3 and the function mass for each technical function in Section 5.3.5. The results for each function are shown in Figure 4. In this step, the results have to be interpreted in order to identify optimisation potentials. For this purpose, interpretation of the results shall be similar to VA. This means that a dilemma arises if the function mass aim is much lower than the function mass. This is because the function needs a lot of mass for its fulfillment but is not that important to the customer. In this case, the designers have to act and resolve this dilemma. The larger the difference between the function mass aim and the function mass, the larger the optimisation

potential according to the idea of VA. If the function mass aim is much larger than the function mass, an important function has been realised in a light way.
For the example under consideration, Figure 4 shows that there is a large difference between the function mass aim and the function mass for the functions of “increase force”, “store energy” and “channel air”. This means that these functions have to either be omitted or realised in a lighter way. The function mass of the functions “compress air”, “suck air”, “channel air into object” and “measure pressure” are all below the function mass aim. This signifies that there is a lesser priority for optimising these functions than for optimising other functions.

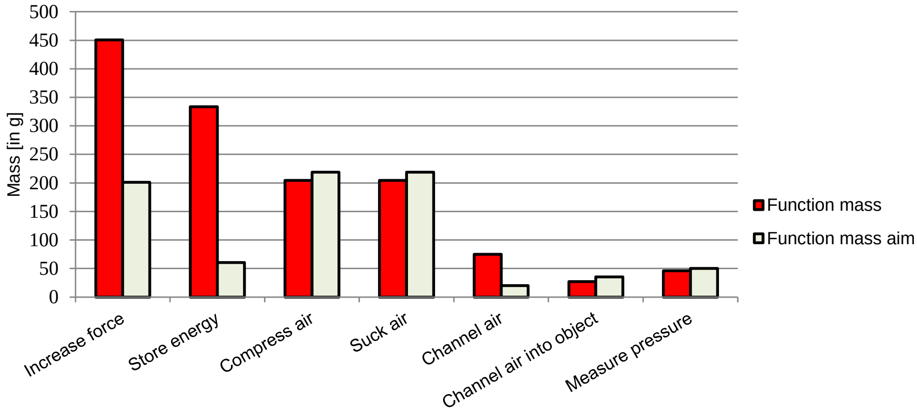


*Figure 4. Comparison of the function mass and the function mass aims*

Another way of interpreting the calculations is shown in Figure 5. The figures show the mass that is realised for the fulfillment of the functions over the factor for the importance of the functions. According to the figure “Recommendation for action” by Posner (2012), which is shown on the right-hand side of Figure 5, the function “store energy” has to be omitted, if it can be omitted, or realised in a lighter way. A difference to the first interpretation is that the function “increase force” has to be optimised, and does not necessarily have to be omitted. In the case of the other functions, the mass which is needed for their fulfillment is not so large that they have a high optimisation potential but it needs to be discussed whether they can be omitted because of their low importance. Both ways of interpreting the calculated results lead in this case to almost the same results and both show the relations between functions and mass which is needed for their fulfillment.

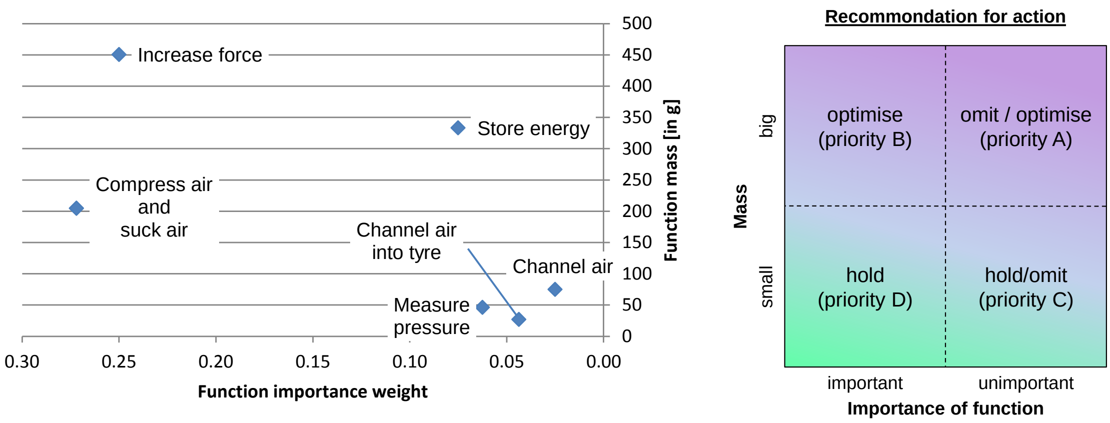


*Figure 5. Importance and mass of function according to Posner (2012)*

## 5.4 Collecting and finding solution ideas

In this step, the analysis results of the first interpretation in Section 5.3.6 will be taken for realising optimisation. The results of the steps before are the basis for a systematic decision by the project team members as to which functions have to be omitted and which functions have to be realised in a lighter way. For generating new ideas, the idea-finding techniques, for example as according to Pahl et al. (2007), can be used.

In the following, the solutions for the functions of the air pump example considered will be discussed.

**Functions: “increase force”, “store energy”, “channel air”**

The optimisation potential analysis found that there is a large deviation between the importance of the function and the mass which is needed to realise it. It is shown that the mass is much too heavy. As such, the project team has to consider whether the functions can be omitted or not. In the case of the portable pump considered, these functions can be omitted.

**Functions: “compress air” and “suck air”**

The mass aims for the functions “compress air” and “suck air” are larger than the mass which is needed for the implementation of these functions. These functions will therefore still be realised in a similar way. However, this does not mean that there is no need for lightweight design for these solutions. Lightweight design has to be applied to these solutions too, such as a lightweight material design.

**Functions: “channel air into object” and “measure pressure”**

The functions “channel air into object” and “measure pressure” fulfil the mass aims and can be retained. The mass optimisation potential analysis of the steps before show which mass is needed for the functions. The project team now has a basis for discussing these functions with their customers. For example, the function “measure pressure” is perhaps not necessary for each application of the new product. The project team can therefore decide systematically whether the function should be realised or if they want to design a product without that function and thereby without the mass which is needed for this function.

**A possible solution**

If the ideas developed were realised, a possible solution would be an air pump without any increasing of the force, energy storage, hose or gauge, as shown in Figure 6. This is a very simple example of a portable solution for the air pump.

*Figure 6. A possible solution for a portable air pump*

For the following steps in Sections 5.5 to 5.8, the example of the air pump will not be referred to again because these steps are similar to the procedure of Value Analysis according to VDI (2010) and often tested in industrial projects (VDI 2011).

### 5.5 Evaluation of solution ideas and development of holistic proposals

In this step, the developed ideas of the aforementioned steps are combined and further developed. Then the ideas are evaluated based on the requirements which they have to fulfill. The outcomes are work programs which include the ideas to be pursued. In the step for developing holistic proposals, detailed studies are made based on the solution ideas. The solution ideas are further developed to form solutions and then evaluated according to their advantages and disadvantages, necessary investments, risks and so on (VDI 2010).

### 5.6 Presentation of proposals, making decisions and realisation

In this step, the solutions to be proposed are selected and realisation programmes for these solutions are elaborated. The decision basis for the decision makers will be prepared. By presenting the decision basis to the decision makers, a decision can be obtained. In this step, all persons involved in the project have to be informed about the decisions made by the decision makers and about the further procedure. Actual results have to be compared with the forecasted results and achieved results have to be communicated (VDI 2010).

## 6 DISCUSSION

Functions, which customers do not want, will not contribute to the product’s success but they will contribute to the total mass of the product. Analysis of the importance of the functions and the mass which is needed for their fulfillment is therefore very important. FMA is a method for the analysis of mass optimisation potentials, functions and the mass which is needed for fulfilling these functions. The operationalised method presented, FMA, closes the gap in the state of art.

The method was developed in science and theory. The next step is to apply it to real industrial applications. Feedback from this use will show whether the method is effective in industry and it will allow for further development of the method. With the method in its current state, there are still a number of question marks. For instance, there is a large amount of subjective influence by the project members who conduct the VA and FMA and steps such as linking customer-oriented functions to technical functions are imprecise. Nevertheless, several uses in industry demonstrate the practical success of VA, and the idea, steps and methods of FMA were derived from VA. This is an indication that FMA could also work in practice despite its dependence on the subjective influence of its users.

## 7 CONCLUSION AND OUTLOOK

The method presented shows how VA can be applied in terms of mass instead of costs. With the transferred VA, which is called Functions Mass Analysis (FMA), the project members can analyse existing products and use this analysis for developing lightweight products. The method assists in the analysis of the importance of functions for the customers and the analysis of the mass needed to fulfill these functions. Based on this information, the project members are able to adapt their products to meet customer needs. Functions which need a high mass for their fulfillment and which are not that important to the customer can be omitted. This reduction of the less important functions opens new possibilities for lightweight design. The advantages of FMA, such as using an interdisciplinary team for the project, developing a common understanding of the product, analysing the importance of functions and visualising the resources which are needed for function fulfillment are integrated in order to follow up on the success of VA. The next stage of development of this method has to be extensive evaluation of the method as already discussed. Moreover, introducing the consideration of mass distribution and moment of inertia will support holistic mass optimisation.


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### REFERENCES


Blessing, L. and Chakrabarti, A. (2009) *DRM, a Design Research Methodology*. London: Springer Verlag.

Broderick, R. (1992) The application of value analysis to some Ariane 5 launcher sub-systems. *Proceedings of the Institution of Mechanical Engineers, Part G, Journal of Aerospace Engineering*, Vol. 206, pp 63-70.

Deutsches Institute für Normung (2002) *DIN EN 12973 Value Management*. Berlin: Beuth Verlag.

Feyerabend, F. (1990) *Methodische Gewichtsreduzierung: Am Beispiel von Industrierobotern*. dissertation, Paderborn, University of Paderborn.

Henning, F. and Moeller, E. (2011) *Handbuch Leichtbau*. München: Carl Hanser Verlag.

Kermode, G. , Sivaloganathan, S. and Shahin, T. (1998) Value analysis – the technique: state of the art and future directions. *Proceedings of the Institution of Mechanical Engineers: Part B, Journal of Engineering Manufacture*, Vol. 214, pp 41-47.

Pahl, G., Beitz, W., Feldhusen, J. and Grote, K.-H. (2007) *Engineering Design: A systematic approach, third edition*. London: Springer Verlag.

Ponn, J. and Lindemann U. (2011) *Konzeptentwicklung und Gestaltung technischer Produkte*. Heidelberg: Springer Verlag.

Posner, B., Keller, A., Binz, H. and Roth D. (2012) Holistic lightweight design for function and mass: A framework for the Function Mass Analysis, *12th International Design Conference 2012*, Dubrovnik, Croatia, May, 21-24, Zagrep/Glasgow: Andreasen, M.; Birkhofer, H.; Lindemann, U.; Culley, S.; Marjanovic, D., pp. 1071-1080

Verein Deutscher Ingenieure (2010) *2800 Value Analysis*. Düsseldorf: Beuth Verlag.

Verein Deutscher Ingenieure (2011) *Wertanalyse – das Tool im Value Management*. Berlin: Springer Verlag.

Bendsøe, M. and Sigmund, O. (2004) *Topology optimization: theory, methods and applications*. Berlin, Springer Verlag.