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DESIGN TO COST: NEW IMPULSES FOR TARGET COSTING

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1. Introduction

Due to rising cost pressure, resulting from tight target costs in today's products, target costing constantly grew in importance since its introduction in Europe by the end of the 1980s.

As target costing provides a tool kit for the planning and control of product costs different characteristics of the approach developed over the years with diverse methods being applied in the course of the target costing process. The authors of this contribution enrich classic target costing with a costing method developed for the cost estimation of individualized products and a multiple-domain approach considering numerical aspects. The result is an approach for the target costing of functionality improvements and/or extensions of structurally complex mechatronic products.

Among others it offers special potentials regarding the deduction of cost reducing actions in consideration of different aspects such as functionality, component and process structure.

2. Related Research

Target Costing can be regarded as the overriding method used in cost management of technical products. The goal of target costing is to establish continuous market-oriented cost targets, implemented directly throughout the enterprise and its subsections following result-oriented and transparent cost control measures. Within the target costing process three phases can be distinguished [Seidenschwarz 1993]. Starting with the product's possible selling price, which can be achieved in the market, target costs are then calculated by subtracting the desired profit margin from this target price. Total target costs are then allocated to customer-relevant functions or properties, as well as to known (previous) component costs. Additionally, the distribution can be allocated to estimated competitors' component costs [Ehrlenspiel et al. 2007]. This provides the basis for development-concurrent cost calculations along with cost reducing concept revisions.

With progress in the design process the calculations are gradually refined. One possibility to document this step-by-step refinement is the method of Individual Pathway Costing (IPC) introduced by [Gahr et al. 2005]. The core of the IPC method is the determination of resource consumption of activities, similar to the principle idea of Activity Based Costing (ABC) [Kaplan et al. 1999]. In addition to ABC or other methods that are based on ABC, the Individual Pathway Costing also explicitly considers costs of bought-in parts. They are handled in the same manner as the other activities within the development and production processes. Having been developed for the cost estimation of individualized products IPC contains a predefined structure of activities in the form of configurable process modules, which have to be carried out in order to develop and produce a product according to its individual order procedure. IPC is characterised by three aspects: the structure of individual pathways, the determination of resource consumption and the determination of uncertainties in context of cost estimation [Gahr 2006].

As about 80% of product development is not new development [Pahl et al. 2005] the principle of reusing process modules and even complete process pathways has the potential to be adapted to a wide range of applications. Possible areas of application would be the functionality improvement or extension of an existing product basis.

As mentioned before, the development-concurrent cost calculation is a catalyst for cost reducing concept revisions. However, it is often difficult to identify the essential cost drivers within a complex product and process structure especially in the case of mechatronic products. This is because complexity drivers and cost drivers are very closely interlinked and can be found within the functional, component and process structure [Braun et al. 2007].

In order to cope with this challenge several approaches can be found in research that link different aspects of product and process with the resulting costs through matrices. [Vivace 2004] for example link requirements to process costs via functions and components (Figure 1a). A similar approach was introduced by [Zrim et al. 2006] who link functions to process costs via components (Figure 1b).

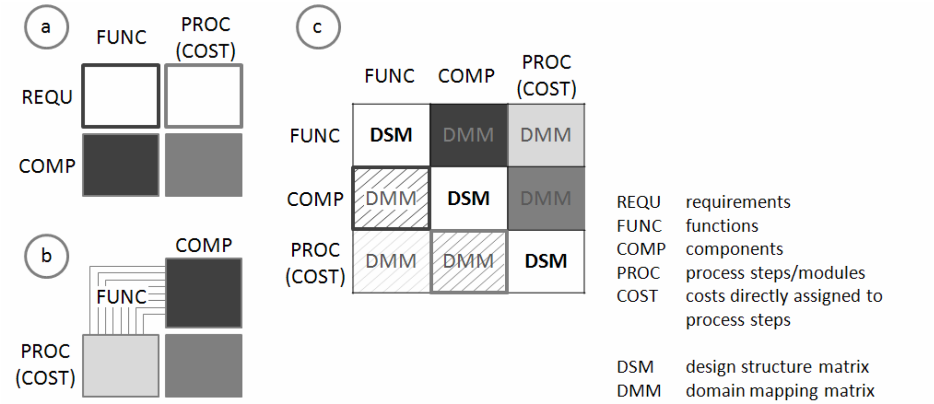


Figure 1. Comparison of matrix oriented approaches to model the dependencies of product functions, components and costs: (a) [Vivace 2004], (b) [Zrim et al. 2006] and (c) model of the contribution at hand

Systematising these approaches leads to their transformation into a Multiple-Domain Matrix (MDM) [Braun et al. 2007]. There the domains are arranged in a symmetric matrix [Maurer 2007]. Networks consisting of only one domain type, like e.g. the functional structure, are located on the matrix diagonal (according to the approach of the design structure matrix, DSM [Steward 1981]). The rest of an MDM is made up of networks that describe the interaction of two different domains (according to the approach of the domain mapping matrix, DMM [Danilovic et al. 2004]). The MDM presented in Figure 1c covers the domains introduced by [Vivace 2004] and [Zrim et al. 2006] and additionally adds the possibility to document inter-domain relationships (functional structure, component structure and process structure).

In order to completely model the dependencies and to allow for cost analysis, [Lindemann 2007] claims an extension of the MDM approach by integrating further data such as a quantification of the relationships. A first contribution to the numerical extension of the MDM approach is presented by [Biedermann et al. 2007].

3. Aim

[Biedermann et al. 2007] demonstrated that the MDM quantification opens the possibility for numerical analysis in addition to the already known structural analysis. This can be especially valuable for the cost analysis of products with a high structural complexity.

The Individual Pathway Costing method is an approach originally developed for individualized products that in addition seems to have potential for the use for functionality improvement or extension of an existing product basis.

It is the authors' aim to analyse both approaches' applicability for the support of the target costing process of complex mechatronic products. Thereby the focus lies on the gradually refined development-concurrent cost calculations along with the resulting cost reducing concept revisions.

The resulting approach should support a continuous target costing process that allows for the parallel and consistent identification of function costs, component costs and process costs. This is especially important as target costs are often set for customer relevant functions but the estimated costs are bound to components and process steps.

The time and effort for cost estimation should be reduced through the reuse of process modules and paths. This growing process building set should then provide the basis for the maintenance and creation of product variants.

In addition the approach should support the identification of cost drivers in the different involved and strongly interlinked domains: functional domain, component domain and process domain. Thus, the deduction of the resulting course of action should be simplified and impacts of resulting changes should be easy to trace through the domains.

4. Method

The description of the developed approach has been structured according to its essential steps. At first target costs and original data of the example application are introduced. Then the cost estimation including the determination of uncertainties and the comparison of target and estimated costs are explained. Finally the deduction of actions on the basis of the cost analysis is presented.

4.1 Example Application and Target Costs

The developed approach will be presented and evaluated on the basis of a position controlled camera platform for an optical sensor system. This example of a mechatronic system is used for 3D motion stereo. In motion stereo, depth information of a scene is generated by taking two pictures from different positions within a short time period. The camera of the example application is therefore moved along a vertical axis by means of a telescope construction (Figure 2a).

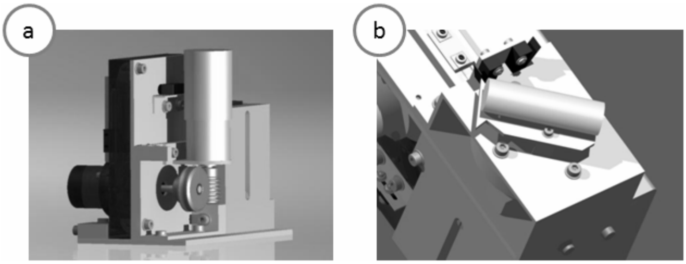


Figure 2. Example application: position controlled camera platform

The functionality of this basic module should now be expanded for night shots. The applied camera system should remain untouched by this modification. Therefore structured light was chosen as luminous source allowing the extraction of features as well as gathering depth information using triangulation (Figure 2b). Thus, the requested functionality *allow for night shots* can be broken down into two sub functions: *emit structured light* and *disperse light over detection area*. The target cost for the new function is fictitiously set to 100 EUR for development and production at a number of 50 pieces. For the presented application the target costs are allocated according to the customer-relevant functions resulting in 60 EUR for *emit structured light* and 40 EUR for *disperse light over detection area*. Having these target costs on hand the presented approach now assists in the determination of the estimated costs from the first calculation on.

4.2 Original Data

From the development and production of the basic camera platform several information is available in form of a Multiple-Domain Matrix as shown in Figure 3. The functional structure describes the interaction of the camera platform's functions. The model also contains information about which component realises which function. There are three specifications of the component structure: One documents the change impacts between the systems' components. The second describes the interaction of the components due to the collective fulfilment of a function. Whereas the third specification contains the information about component links due to the collective handling in a process step. Numbered 4 in Figure 3 is the DMM that assigns the process steps to the components they create. Last the MDM contains information about the process structure.

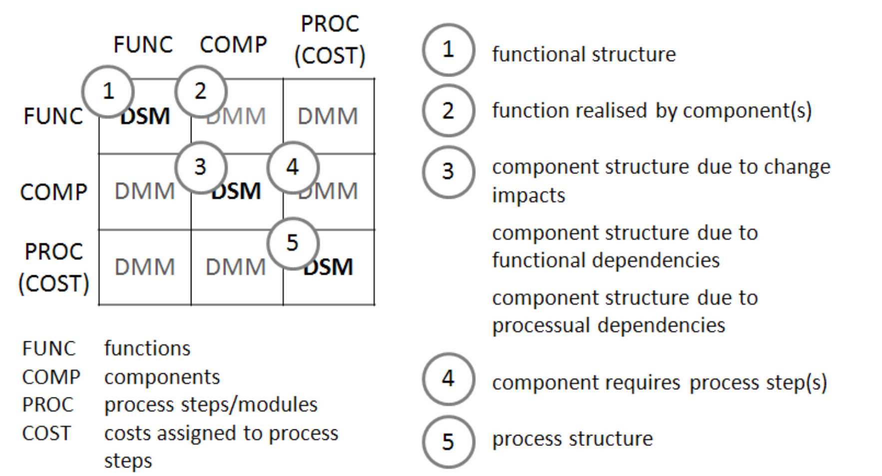


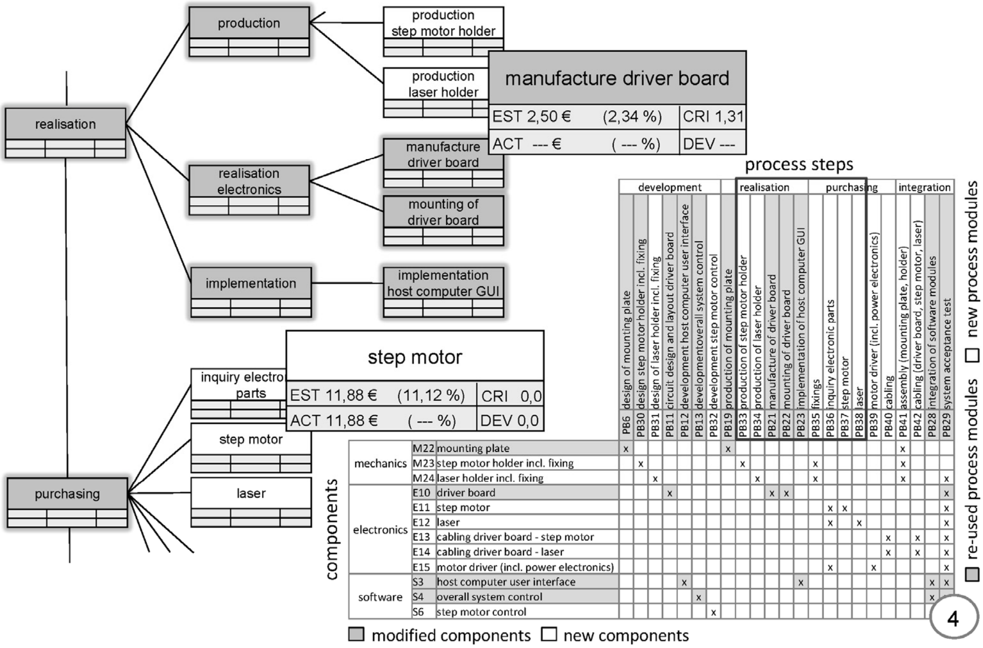
Figure 3. Structure of original data

In addition to the information included in the MDM the hierarchally refined process steps are documented in form of a process tree consisting of several process modules filled with cost data from actual costing.

4.3 Cost estimation

The first step in the described cost estimation process is the identification of components that have to be modified and components that have to be added to the component structure in order to fulfil the requested functionality (bottom of Figure 4). In order to identify possible change impacts that lead to changes of components that are not directly and obviously affected by the functionality extension the corresponding component structure is used. In case of a functionality improvement information about the interaction of components due to their collective fulfilment of a function is of great help.

Through the linkage of the components that have to be modified and the process steps that were necessary for their original construction it becomes apparent which process steps have to be repeated with differing parameters in the course of the functionality extension. In the presented example the *mounting plate* has to be modified to support the *step motor holder*. Therefore the *design of the mounting plate* has to be extended and its *production* has to be changed. The corresponding process modules can be chosen from the already existing process building set and added to the hierarchical process tree (upper left of Figure 4). New process modules (resulting from new components) such as *production of step motor holder* in our example have to be created and linked to the corresponding component(s). Matrix and process tree have to be automatically linked to allow for a parallel editing. Figure 4 also displays the integration of bought-in parts in the hierarchical process tree in form of the step motor as its costs have to be added to the overall activities' costs.



			development								realisation					purchasing						integration			
			PB6 design of mounting plate	PB30 design step motor holder incl. fixing	PB31 design of laser holder incl. fixing	PB11 circuit design and layout driver board	PB12 development host computer user interface	PB13 developmentoverall system control	PB32 development step motor control	PB19 production of mounting plate	PB33 production of step motor holder	PB34 production of laser holder	PB21 manufacture of driver board	PB22 mounting of driver board	PB23 implementation of host computer GUI	PB35 fixings	PB36 inquiry electronic parts	PB37 step motor	PB38 laser	PB39 motor driver (incl. power electronics)	PB40 cabling	PB41 assembly (mounting plate, holder)	PB42 cabling (driver board, step motor, laser)	PB28 integration of software modules	PB29 system acceptance test
mechanics	M22	mounting plate	x							x												x			
	M23	step motor holder incl. fixing		x							x					x						x			
	M24	laser holder incl. fixing			x							x				x						x			x
electronics	E10	driver board				x							x	x											x
	E11	step motor															x	x							x
	E12	laser															x		x						x
	E13	cabling driver board - step motor																			x		x		x
	E14	cabling driver board - laser																			x		x		x
	E15	motor driver (incl. power electronics)															x			x					x
software	S3	host computer user interface					x								x									x	x
	S4	overall system control						x																x	[illegible]
	S6	step motor control							x																

Figure 4. Cut-out of the hierarchical process tree and the domain mapping matrix documenting the linkage of components and process modules

The hierarchical arrangement of activities and parts is divided in three layers: the macro-, the micro- and application-pathway [Gahr et al. 2005]. The macro-path contains essential phases, involved in the general order processing. In the presented example these are *development*, *realisation*, *purchasing* and *integration*. The macro-path is aligned in vertical order and detailed with further process modules in the horizontal direction. The resulting micro-path can contain more than just one layer, as illustrated in the example. The detailing of the micro-pass is a gradual and iterative process throughout the complete development phase. Taken as a whole, the last process modules in the horizontal direction of each branch form the application-pathway at the currently available level of detail.

The application-pathway's process modules are then filled in with cost information. As a result, the costs of the application-pathway are calculated by aggregation of the process modules' costs. The cost information includes estimated costs (EST) and actual costs (ACT).

Estimated costs of process modules are determined by valuing their resource consumption e.g. labour, machinery or material. At least one sort of resource consumption must be assigned to every process module. In case of re-used process modules the sort of resource consumption is already known or otherwise, it has to be defined. In this manner all resource consumption, directly linked to the regarded functionality extension, is determined. The goal is to use the resulting cost information in making design decisions and concept revisions rather than for business cost accounting purposes only.

In Figure 4 the process module *manufacture of driver board* is highlighted. The resource consumed is the machinery with a cost rate of 25 €/h. Multiplying this rate with the expected duration of 0.1 h results in 2.50 € for the *manufacture of driver board*.

In order to enhance the quality of cost estimates IPC considers uncertainties in the calculation by using range estimates and triangular distribution [Gahr et al. 2005]. The range estimate considers three values: an optimistic-, a pessimistic- and a modal-value for the resource consumption. In order to display the criticality $CRIT(PM_i)$ or risk factor of a process module PM_i the variance $V(PM_i)$ of these three values is calculated and multiplied with the quotient of the expected-value of the process module $E(PM_i)$ and the sum of the expected-values of all the process modules of the application-path $\sum_{n=1}^{j} E(PM_n)$ [Gahr 2006]:

$$CRIT(PM_i) = V(PM_i) \cdot \frac{E(PM_i)}{\sum_{n=1}^{j} E(PM_n)}$$

Process modules with a high criticality have a high uncertainty regarding the quality of the cost estimation and at the same time a high portion of the overall costs.

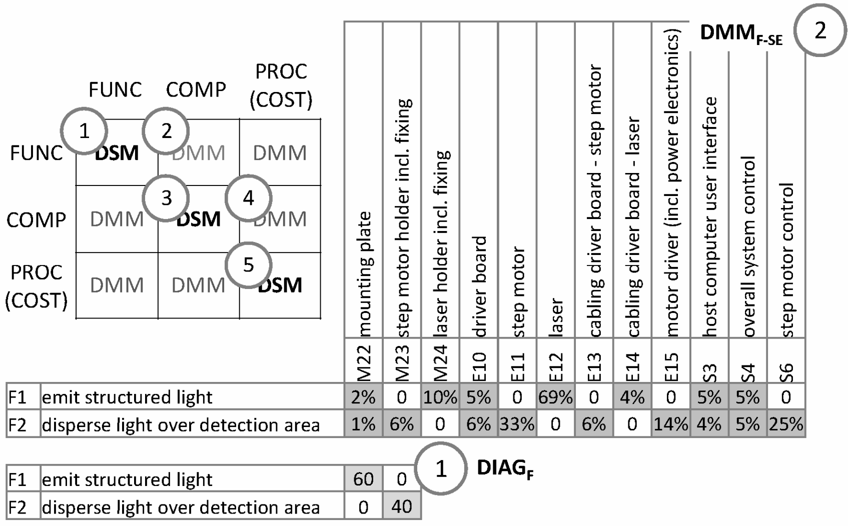
In the case of bought-in parts actual costs can be documented as soon as they have been inquired. The other process modules' actual costs cannot be determined until the activity is completed. Information on actual costs can then be re-used in order to assist in the cost management of following order processings.

4.4 Comparison of target and estimated costs

Having now target costs on the one hand and estimated costs on the other, both have to be compared in order to deduce adequate revision steps. In order to achieve comparable values, the costs have to be transformed to the same reference basis. Thus, the function based target costs as well as the process module based estimated costs are transformed to component based costs.

The principle of this transformation will exemplarily be explained for the conversion of the function based target costs:

Basically, two aspects are necessary for the transformation: 1) the target costs of the functions and 2) the components' significances to the functions. Whereby, it is possible, that the degree of fulfilment differs between two components that contribute to the same function [Ehrlenspiel et al. 2007]. The standard transformation of function based target costs to component based target costs can also be found in [Ehrlenspiel et al. 2007].



		M22 mounting plate	M23 step motor holder incl. fixing	M24 laser holder incl. fixing	E10 driver board	E11 step motor	E12 laser	E13 cabling driver board - step motor	E14 cabling driver board - laser	E15 motor driver (incl. power electronics)	S3 host computer user interface	S4 overall system control	S6 step motor control
F1	emit structured light	2%	0	10%	5%	0	69%	0	4%	0	5%	5%	0
F2	disperse light over detection area	1%	6%	0	6%	33%	0	6%	0	14%	4%	5%	25%

F1	emit structured light	60	0
F2	disperse light over detection area	0	40

Figure 5. Original data for the estimation of component based target costs

Here we are breaking new ground as we execute this transformation with the help of a quantified multiple-domain matrix. As mentioned above, the handling of cost information in the MDM-notation opens special potential for the development of structural complex products. It enables the handling of structural and numerical information in the same data basis at the same time. This allows for structural as well as numerical (cost) analysis. So for example it becomes possible to determine with one single calculation which parts are linked through their collective contribution to a function and how much these parts cost. Additional information provided assists in the following deduction of actions. The advantages of this concept will become clear in the course of the subsequent example application.

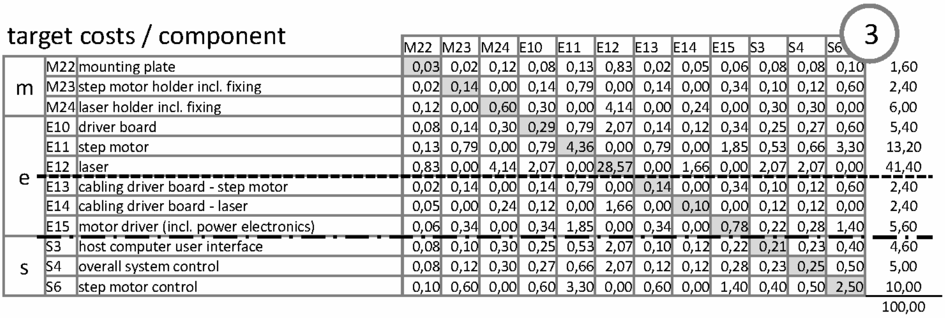
In order to consider the components' significances and the functions' target costs they first have to be modelled [Biedermann et al. 2007]. A component's significance to a function can be modelled by the component's proportion of the function's fulfilment. The percentage is included by weighing the domain-mapping matrix which describes the mapping between functions and components. The resulting matrix DMM_{F-C} for this example is given in Figure 5.

The function based target costs cannot be modelled as easily as the component significance. Two requirements exist when considering costs [Biedermann et al. 2007]. The integration of an attribute (costs) must not change the resulting network. Otherwise all structural analyses would be invalid. Meaning, in the example of target cost transformation that the functional structure (In the depicted example the functional structure consists of only two interlinked functions.) should not be influenced by the integration of cost attributes. The second requirement applies specifically to costs. The costs must remain consistent i.e. the total sum of all costs must remain identical in all considerations. Both requirements are fulfilled if the costs are modelled as a diagonal matrix $DIAG_F$ (Figure 5).

Now that the needed information is integrated in the MDM-notation the required component based target costs can be computed by the following equation [Biedermann et al. 2007]:

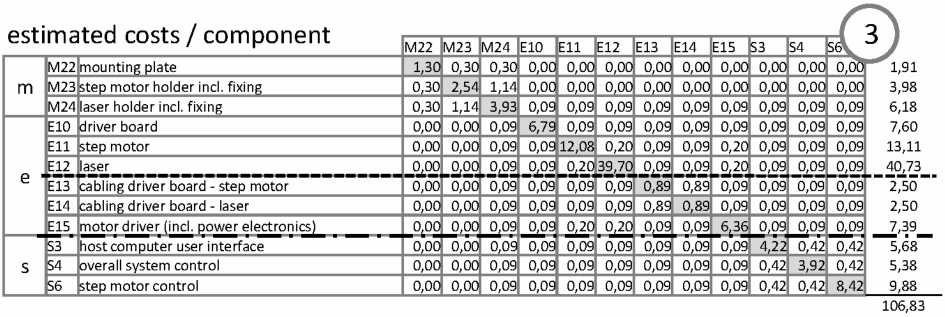
$$DSM_{C(FD)} = DMM_{F-C}^{T} \cdot (DIAG_F \cdot DMM_{F-C})$$

The row sum of the resulting design structure matrix $DSM_{C(FD)}$ equals the corresponding component's target cost (Figure 6). Additionally the matrix contains the structural information which components are linked through their collective fulfilment of a function. Two components are linked when the value of their column and row cross points does not equal zero.



target costs / component

			M22	M23	M24	E10	E11	E12	E13	E14	E15	S3	S4	S6	
m	M22	mounting plate	0,03	0,02	0,12	0,08	0,13	0,83	0,02	0,05	0,06	0,08	0,08	0,10	1,60
	M23	step motor holder incl. fixing	0,02	0,14	0,00	0,14	0,79	0,00	0,14	0,00	0,34	0,10	0,12	0,60	2,40
	M24	laser holder incl. fixing	0,12	0,00	0,60	0,30	0,00	4,14	0,00	0,24	0,00	0,30	0,30	0,00	6,00
e	E10	driver board	0,08	0,14	0,30	0,29	0,79	2,07	0,14	0,12	0,34	0,25	0,27	0,60	5,40
	E11	step motor	0,13	0,79	0,00	0,79	4,36	0,00	0,79	0,00	1,85	0,53	0,66	3,30	13,20
	E12	laser	0,83	0,00	4,14	2,07	0,00	28,57	0,00	1,66	0,00	2,07	2,07	0,00	41,40
	E13	cabling driver board - step motor	0,02	0,14	0,00	0,14	0,79	0,00	0,14	0,00	0,34	0,10	0,12	0,60	2,40
	E14	cabling driver board - laser	0,05	0,00	0,24	0,12	0,00	1,66	0,00	0,10	0,00	0,12	0,12	0,00	2,40
	E15	motor driver (incl. power electronics)	0,06	0,34	0,00	0,34	1,85	0,00	0,34	0,00	0,78	0,22	0,28	1,40	5,60
s	S3	host computer user interface	0,08	0,10	0,30	0,25	0,53	2,07	0,10	0,12	0,22	0,21	0,23	0,40	4,60
	S4	overall system control	0,08	0,12	0,30	0,27	0,66	2,07	0,12	0,12	0,28	0,23	0,25	0,50	5,00
	S6	step motor control	0,10	0,60	0,00	0,60	3,30	0,00	0,60	0,00	1,40	0,40	0,50	2,50	10,00
															100,00



estimated costs / component

			M22	M23	M24	E10	E11	E12	E13	E14	E15	S3	S4	S6	
m	M22	mounting plate	1,30	0,30	0,30	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,91
	M23	step motor holder incl. fixing	0,30	2,54	1,14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,98
	M24	laser holder incl. fixing	0,30	1,14	3,93	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	6,18
e	E10	driver board	0,00	0,00	0,09	6,79	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,09	7,60
	E11	step motor	0,00	0,00	0,09	0,09	12,08	0,20	0,09	0,09	0,20	0,09	0,09	0,09	13,11
	E12	laser	0,00	0,00	0,09	0,09	0,20	39,70	0,09	0,09	0,20	0,09	0,09	0,09	40,73
	E13	cabling driver board - step motor	0,00	0,00	0,09	0,09	0,09	0,09	0,89	0,89	0,09	0,09	0,09	0,09	2,50
	E14	cabling driver board - laser	0,00	0,00	0,09	0,09	0,09	0,09	0,89	0,89	0,09	0,09	0,09	0,09	2,50
	E15	motor driver (incl. power electronics)	0,00	0,00	0,09	0,09	0,20	0,20	0,09	0,09	6,36	0,09	0,09	0,09	7,39
s	S3	host computer user interface	0,00	0,00	0,09	0,09	0,09	0,09	0,09	0,09	0,09	4,22	0,42	0,42	5,68
	S4	overall system control	0,00	0,00	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,42	3,92	0,42	5,38
	S6	step motor control	0,00	0,00	0,09	0,09	0,09	0,09	0,09	0,09	0,09	0,42	0,42	8,42	9,88
															106,83

Figure 6. Representation and comparison of target and estimated costs

In the same manner the design structure matrix containing information about the components' estimated costs can be calculated. Here the process modules' contributions to the realisation of the components are weighted in the corresponding DMM. The estimated costs are modelled as the diagonal of the DSM documenting the process structure. The resulting DSM is depicted at the bottom of Figure 6.

Comparing the matrices' row sums enables the identification of discrepancies between the target and estimated costs of the components. So for example the *motor driver* runs the risk of exceeding the target costs if it won't be reworked or a cheaper component supplier is found – whereas the *laser* is already in budget.

4.5 Deduction of actions

The resulting networks offer several possibilities for analyses. To begin with, the established comparison of a component's target and estimated costs is enabled. Similar to common target costing approaches the matrices offer the possibility to identify components that are about to exceed target costs and therefore have to undergo rework of any kind.

However, where other methods end the presented approach starts to display its potentials: In the target cost matrix the row sum of a component – its target costs – is split into costs for the part itself, and into costs for its relations to other parts. Costs for the part itself can be found on the matrix's diagonal. Thus, it becomes possible to judge a components value in comparison to its interfaces to other components [Biedermann et al. 2007]. The interfaces itself can also be compared. As a result necessary rework can focus on the core component or concentrate on its important interfaces.

In a similar manner the estimated cost matrix can be analysed. Here the costs of a component are split into costs spent in process modules that are only necessary to produce the considered component and costs spent in process modules that are required by more than the considered component. Figure 6 (in combination with Figure 5) shows that the *motor driver*'s costs are to 86% made up of its acquisition costs and only 14% fall upon process modules shared with the *laser*, the *step motor* (*inquiry electronic parts*) and other components (*system acceptance test*). Thus, in order to reduce the *motor driver*'s costs it makes more sense to concentrate on its acquisition costs than on the other process modules' costs. This is especially true if like in this case the estimated costs of components related through process modules – *laser* and *step motor* – do not exceed their cost target.

Another analysis and starting point for concept revisions is the information about two or more components being related through their collective fulfilment of a function. If several components, related through a function, are expected to exceed target costs it is worth considering replacing the chosen working principle (physical effect) and with that substituting the corresponding components.

Through the documentation of the components' reciprocal change impacts in form of another DSM (Figure 3), impacts of changes resulting from cost reducing concept revisions can be traced through the product structure [Braun et al. 2007].

It has to be mentioned, that in case of a high criticality (Equation 1) of a process module linked to a component expected to exceed target costs efforts have to be made to first improve the quality of the calculation before mayor changes of the product concept are induced.

5. Conclusion and Future Work

It has been shown, that the enhancement of common target costing approaches by principles of Individual Pathway Costing together with the cost modelling in form of quantified multiple-domain matrices offers indeed additional potentials. The deduction of cost reducing actions in consideration of different aspects such as functionality, component und process structure is significantly improved. The information collected in the course of, for example, a functionality extension can in the future be used in order to assist in the calculation and cost-efficient development of other variants of the same product basis. The integration of range estimates improves the quality of cost estimates as they are proven to be more reliable then single point estimates [Neff 2002]. Ranking the process modules according to their risk factor, the need for reconsidering the estimated values respectively the estimated range becomes apparent [Gahr et al. 2005]. Impacts of cost reducing changes can be traced easily through the whole network through the consistent documentation of all relevant information in form of a multiple-domain matrix [Braun et al. 2007]. Thus, the approach has proven its principle qualification for assisting in the development of complex products that are very likely not to exceed today’s tight target costs. Figure 7 depicts the result of the product development that served as example in this contribution.

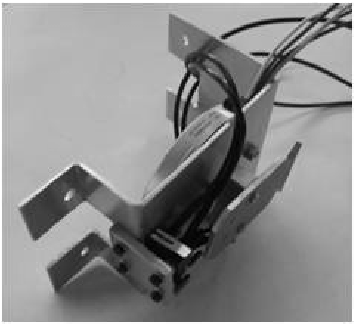


Figure 7. Developed module for the controlled emission of structured light

Nevertheless it has to be mentioned, that the quantification of for example a component’s contribution to a function always holds subjectivity. Therefore the results of the calculations should not be taken for granted without questioning. A possibility to ensure the results would be a sensitivity analysis where the component’s weights are varied. Additional to the target costs’ division according to costs for customer-relevant functions a division according to known (previous) component costs and estimated competitors’ component costs should be considered.

Future work on cost-efficient design of complex mechatronic products will concentrate on the identification of cost reducing potentials. The presented analysis methods are a first step in this direction. However following approaches will attend to earlier phases of product development and already assist in the concept decision. On the basis of structure and cost analyses of mechatronic products it is intended to deduce directives for the cost-efficient design of complex mechatronic products.

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