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The determination of function costs to achieve success-oriented design of engineering products – theory and application

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1 Introduction

1.1 The Elements of success-oriented engineering design

Engineering design can be defined as a process of transforming the customer's statement of requirements into a full description of the proposed engineering product (ref. Hubka 1987, p. 31 and Pahl/Beitz 1996). It is obviously the goal of all engineering design to produce a successful product. Success can be measured in comparing the turnover (price multiplied by quantity sold) with the costs generated for the company by this turnover (see **Fig. 1**). To analyse and predict product success, representative figures will be required for the inputs and outputs of the production process – i.e., not only for the generation of the goods (outputs) but also for the consumption of resources (inputs). In the engineering design context, it is then a question of how best to influence each of the figures (that for the turnover and that for the cost of the turnover, which are both success factors) so as to improve the product's eventual success. It is possible to change the turnover for the product, i.e. item price and quantity sold, by modifying the product benefit and/or the costs (the latter by modifying the consumption of resources).

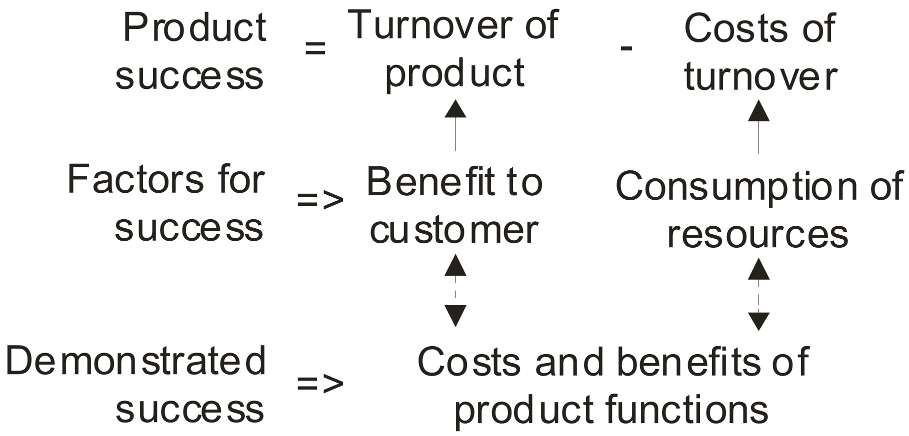

Fig. 1: Functions and their importance as figures of costs and benefits in success-oriented engineering design

The goal of success-oriented design of a product can thus be described as "improvement of product benefit and reduction of resource consumption".[1] To bring this down to operational level in engineering design, it is necessary to break down the goals into targets for individual elements of the product – the components or the functions, for instance (ref. Ansari/Bell 1997, p. 46). If one takes the components, it is easy to get a representative figure for the costs but not for the benefits. That leaves the functions as the only factors susceptible to demonstration of both costs and benefits. The functions are thus of central importance in configuring a product for maximum success (see **Fig. 2**). The benefit which a product owes to its functions will relate to the market segment the product is designed for, and Conjoint Analysis is one way of estimating it (ref. Green/Srinivasan 1978,

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[1] These factors of success are also used when Value Engineering is applied.

Green/Srinivasan 1990). Function costs, on the other hand, have to be obtained from the company where the product is produced. The costs are usually generated by the components the product consists of.

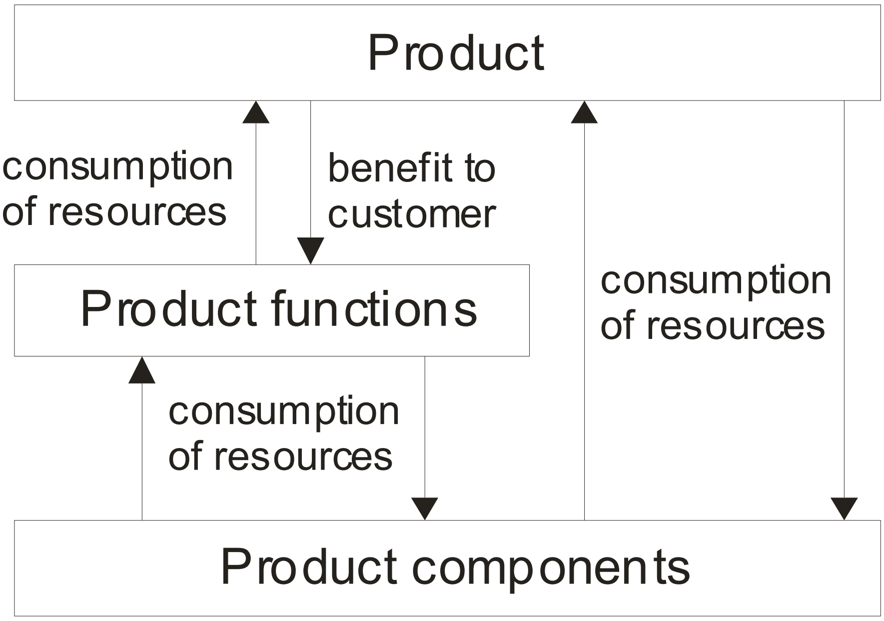

Fig. 2: Principles of cost allocation over a product, its functions and its components

Cost-oriented engineering design, which is to be seen as part of success-oriented design, is at heart a cost-oriented selection of alternatives.[2] The product with the minimum costs is the one likely to cost least by virtue of the choices made for it out of a given array of design options.

There are five steps in the procedure for cost-oriented design (see **Fig. 3**). Step Three is the really vital part. This is when the choice is made of the design alternative thought likely to be the most economical – which is a direct decision about which consumables are in future likely to be most in shortage. Step Two is a prognosis of the costs likely to be generated by the various alternative designs assembled. Step One is to assemble the information both available and relevant to the decision-making process. This information will include not only standard manufacturing costs but also details of life-cycle considerations already necessary to take into account. Once the choice has fallen on one alternative, the product can be turned from an idea into reality and then sold (Step Four). With hindsight (Step Five), the costs actually generated are recorded and can then serve as a foundation for further decision-making (ref. Horngren et al. 2005).

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[2] As cost management can be basically interpreted as decisions about goods in short supply, the practical implication is that options have to be chosen which best meet the relevant targets.

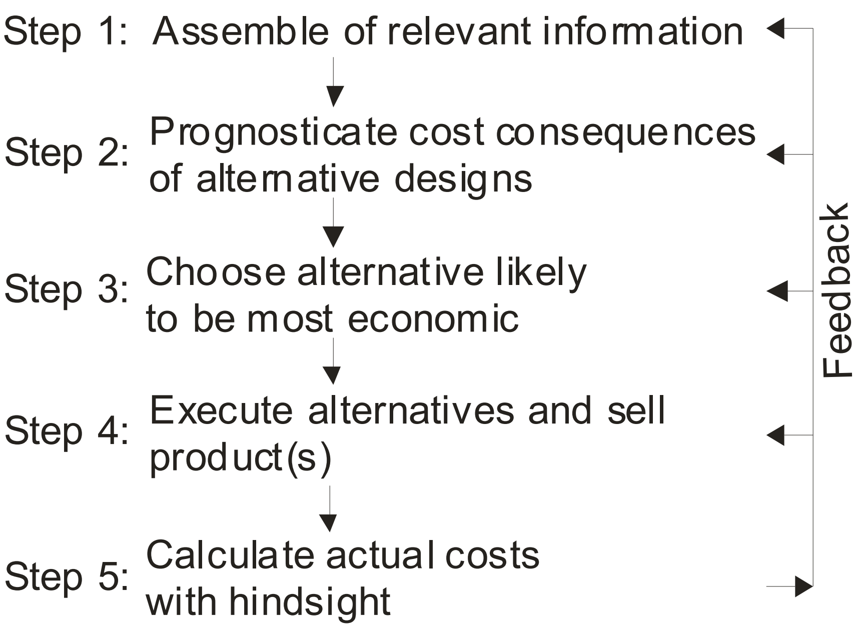

Fig. 3: The general process of cost-oriented engineering design

In the context of the process of cost-oriented design here introduced, cost is assumed throughout the design process to be an active (causative) factor rather than a passive (caused) factor (ref. Blanchard 1978, p. 12).

1.2 The m:n-relationship between functions and components

For the determination of function costs it is necessary to assign the costs from the elements of the structure of components to the elements of the structure of functions. Between both of these structures there is a very complex m:n-relationship. Looking at this relationship the question arises of whether it is possible in principle to determine function costs on the basis of component costs. The problem becomes even more complex if one looks at the fact that for every relation between a single function and a single component weightings are necessary, which are usually estimations.

The two fundamental questions which require an answer when function costs are being determined are

- What function costs are relevant to the purpose underlying the calculation?
- How can the assignment of costs between functions and components be executed in a situation with a complex m:n-relationship?

2 Method for the determination and breakdown of function costs

2.1 Explanation of the relationship between functions and components

Target Costing involves breaking down the Target Costs for the whole product to reflect the individual product functions for operational purposes (ref. Yoshikawa et al. 1993, pp. 51 and Monden 1995, pp. 117). The next stage is to distribute the target costs for the functions over the various components. However, there is usually an m:n relationship between the functions and the components of an engineered product, dictated by the design. What this means is that it is not only possible for one function to be realised by a number of components, but also for a single component to be involved in the realising of a number of functions. Looked at from the mathematical standpoint, what there is here is a relation. A relation is the description given to the link between the elements of a set (in this case, two sets, the set of functions and the set of components). This situation, symbolically exemplified in **Fig. 4**, is the starting point for this paper and its further observations.

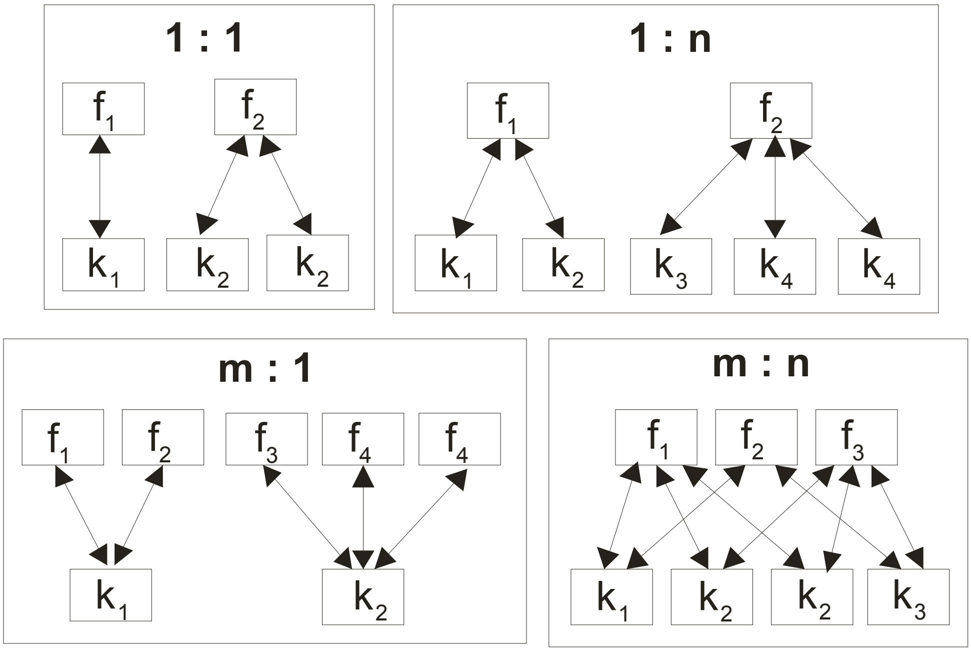

Fig. 4: P relations between functions (f) and components (k) of engineering products

The relationships between functions and components in engineering design is a binary one, as there are only two possibilities, “1” if there is a relation between a particular function and a particular component, and “0” if there is none. The set of functions can be shown in relation to the set of components using a combinatory table which prescribes the link in each case (see **Table 1**). If it is necessary to work on the relations for the functions (as is the case when function costs are being calculated bottom-up, on the basis of component costs), Table 1 will be read downwards from the top. If the components costs are being calculated top-down on the basis of the function costs, the relations will be read off from left to right.

Table 1: Presentation of the m:n-relationship (from Fig. 4) as a table of combinations

	Functions f_i		
Comp. k_j	1	2	3
1	1	1	0
2	1	0	1
2	1	0	1
3	0	1	1

As the case may arise of functions or components appearing twice, a case exemplified by component no. 2 in Fig. 4, these elements should really be entered twice into the matrix. To avoid having to do this, a factor c_{ij} is introduced for the bottom-up case which will show how many identical components k_j are in a relationship with a certain function f_i. The allocation prescription between the column vector of the product functions $F_{(I,1)}$ and the column vector of the product components $K_{(J,1)}$ is equivalent to the multiplication of $C_{(I,J)}$ by $K_{(J,1)}$ and is given in Equation 1. Equation 2 describes the elements of the matrices and Equation 3 contains the figures for the quadratic matrix $C_{(I,J)}$ for the relations shown in Figure 4.

(1) $F_{(I,1)} \rightarrow C_{(I,J)} \cdot K_{(J,1)}$

(2) $$\begin{bmatrix} f_1 \\ f_2 \\ f_I \end{bmatrix} \rightarrow \begin{bmatrix} c_{11} & c_{12} & c_{1J} \\ c_{21} & c_{22} & c_{2J} \\ c_{I1} & c_{I2} & c_{IJ} \end{bmatrix} \cdot \begin{bmatrix} k_1 \\ k_2 \\ k_J \end{bmatrix}$$

(3) $$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 2 & 0 \\ 1 & 0 & 1 \\ 0 & 2 & 1 \end{bmatrix} \cdot \begin{bmatrix} k_1 \\ k_2 \\ k_3 \end{bmatrix}$$

If it is a question of calculating the costs of the functions in the reverse direction (i.e., a top-down calculation), the situation is comparable. The allocation prescription between the column vector of the components and the column vector of the functions is produced, as shown in Equations 4 and 5, by multiplying $H_{(I,J)}$ by $F_{(I,1)}$. Here the factor h_{ij} reveals how many identical functions f_i are in relation to a certain component k_j. Equation 6 demonstrates the situation in the example shown in Fig. 4.

(4) $K_{(J,1)} \rightarrow H_{(I,J)} \cdot F_{(I,1)}$

(5) $$\begin{bmatrix} k_1 \\ k_2 \\ k_J \end{bmatrix} \rightarrow \begin{bmatrix} h_{11} & h_{21} & h_{I1} \\ h_{12} & h_{22} & h_{I2} \\ h_{1J} & h_{2J} & h_{IJ} \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_I \end{bmatrix}$$

(6) $\begin{bmatrix} k_1 \\ k_2 \\ k_3 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 1 & 0 \\ \frac{1}{2} & 0 & \frac{1}{2} \\ 0 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_3 \end{bmatrix}$

To calculate costs of Category Three[3] (bottom-up or top-down) it is now necessary to find a share-of-costs factor a_{ij} / b_{ij}, which will indicate what proportion of the costs of the relevant components related to functions, or functions related to components, is appropriate to be allocated. The share-of-costs factors are assigned to the relevant relations.

The column vector of the function costs $CA_{(I,J)}$ is the product of the matrix $Z_{K(J,1),\,cat\,3}$ and the column vector of the component costs $CA_{(I,J)}$ (see Equations 13 and 14 in **Table 2**), whereby the matrix c_{ij} consists of the factors a_{ij} and the share-of-cost factors $Z_{F(I,1),\,cat\,3}$ allocated.

For the reverse case, the calculation of component costs on the basis of the function costs, Equation 15 or 16 can be applied. The column vector of the component costs $HB_{(I,J)}$ is composed of the product of the $Z_{F(I,1),\,cat\,3}$ matrix and the column vector of the function costs, $Z_{K(J,1),\,cat\,3}$. The h_{ij} matrix contains the factor b_{ij} and the share-of-costs factor $HB_{(I,J)}$. This share-of-costs factor indicates what proportion of the costs of a function is to be attributed to the relevant component.

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[3] See also table 2 on the subject of categorising function and component costs.

Table 2: Important equations for the determination and breakdown of functions costs. The index "T" in the equations 9 and 11 indicates the transposed matrix

Categories	Functions	Components
Category One	(7) $z_{f_{i,cat\,1}} = ko_{ij} = \sum_{u=1}^{U} ko_{iju\circ}$	(8) $z_{k_{j,cat\,1}} = ko_{ij} = \sum_{u=1}^{U} ko_{iju\circ}$
Category Two	(9) $z_{f_{i,cat\,2}} = KO_{(1,J)} \cdot C^{T}_{(1,J)}$ (10) $z_{f_{i,cat\,2}} = \begin{bmatrix} ko_{i1} & ko_{i2} & ko_{iJ} \end{bmatrix} \cdot \begin{bmatrix} c_{1i} \\ c_{2i} \\ c_{Ji} \end{bmatrix}$	(11) $z_{k_{j,cat\,2}} = KO^{T}_{(I,1)} \cdot C_{(I,1)}$ (12) $z_{k_{j,cat\,2}} = \begin{bmatrix} ko_{j1} & ko_{j2} & ko_{jI} \end{bmatrix} \cdot \begin{bmatrix} c_{1j} \\ c_{2j} \\ c_{Ij} \end{bmatrix}$
Category Three	(13) $Z_{F_{(I,1),cat\,3}} = CA_{(I,J)} \cdot Z_{K_{(J,1),cat\,3}}$ (14) $\begin{bmatrix} z_{f_1} \\ z_{f_2} \\ z_{f_I} \end{bmatrix} = \begin{bmatrix} c_{11} \cdot a_{11} & c_{12} \cdot a_{12} & c_{1J} \cdot a_{1J} \\ c_{21} \cdot a_{21} & c_{22} \cdot a_{22} & c_{2J} \cdot a_{2J} \\ c_{I1} \cdot a_{I1} & c_{I2} \cdot a_{I2} & c_{IJ} \cdot a_{IJ} \end{bmatrix} \cdot \begin{bmatrix} z_{k_1} \\ z_{k_2} \\ z_{k_J} \end{bmatrix}$	(15) $Z_{K_{(J,1),cat\,3}} = HB_{(I,J)} \cdot Z_{F_{(I,1),cat\,3}}$ (16) $\begin{bmatrix} z_{k_1} \\ z_{k_2} \\ z_{k_J} \end{bmatrix} = \begin{bmatrix} h_{11} \cdot b_{11} & h_{21} \cdot b_{21} & h_{I1} \cdot b_{I1} \\ h_{12} \cdot b_{12} & h_{22} \cdot b_{22} & h_{I2} \cdot b_{I2} \\ h_{1J} \cdot b_{1J} & h_{2J} \cdot b_{2J} & h_{IJ} \cdot b_{IJ} \end{bmatrix} \cdot \begin{bmatrix} z_{f_1} \\ z_{f_2} \\ z_{f_I} \end{bmatrix}$
Category Four	(17) $z_{f_{i,cat\,4}} = \sum_{j=1}^{J} (z_{k_{j,cat\,3}} \cdot c_{ij} - z_{k_{j,cat\,2}}) + z_{f_{i,cat\,2}}$	-
	a-weightings	b-weightings
Cost weightings	(18) $a_{ij} = \frac{ko_{ij} \cdot c_{ij}}{z_{k_{j,cat\,2}}}$	(19) $b_{ij} = \frac{z_{k_{j,cat\,3}} \cdot c_{ij}}{z_{f_{i,cat\,3}}} \cdot \mathrm{a}_{\mathrm{ij}}$

The m:n relationship considered so far represents the general case, in which one function can be related to a variety of components and one component to a variety of functions. Now follows a consideration of the three special cases, a 1:1 relationship, a 1:n relationship and an m:1 relationship. These are depicted in Figure 4 in the form in which they can appear in principle.[4]

The 1:1 relationship is from the point of view of cost calculation the simplest case of a relation between the functions to be performed by a technical product and the components required for their performance. Reading off the combination table from the top down, it is clear that each function stands in relation to a single or to several identical components.

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[4] The literature describes the four potential types of relationship, m:n, 1:n, m:1 und 1:1 (Yoshikawa et al. 1993, p. 53).

The same is true for this type of relation if **Table 3** is read from left to right. Each component is related to only a single or to several identical components.

Table 3: Table of combinations for the fictive 1:1-relationship from figure 4

Comp. k_j	Function f_i	
	1	2
1	1	0
2	0	1
2	0	1

If the combination table is expressed as a matrix, the 1:1 relation is clear from the fact that in each row and each column of $C_{(I,J)}$ and $H_{(I,J)}$ only one field is not equal to zero, i.e. represents an actual relationship. An example of this can be found in equations 20 and 21 for the situation shown in Fig. 4.

$$\begin{bmatrix} f_1 \\ f_2 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 0 \\ 0 & 2 \end{bmatrix} \cdot \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} \tag{20}$$

$$\begin{bmatrix} k_1 \\ k_2 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 0 \\ 0 & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \end{bmatrix} \tag{21}$$

The nature of the 1:1 relationship means that the costs of components do not have to be split over two or more different functions and the costs of functions do not have to be distributed across two or more components. The share-of-costs factors b_{ij} and a_{ij} can thus only have one of the two values, “0” (no relation present) and “1” (relation exists) – as shown in Equations 22 and 23.

$$\begin{bmatrix} z_{f_{1,\,cat\,3}} \\ z_{f_{2,\,cat\,3}} \end{bmatrix} = \begin{bmatrix} 1 \cdot 1 & 0 \cdot 0 \\ 0 \cdot 0 & 2 \cdot 1 \end{bmatrix} \cdot \begin{bmatrix} z_{k_{1,\,cat\,3}} \\ z_{k_{2,\,cat\,3}} \end{bmatrix} \tag{22}$$

$$\begin{bmatrix} z_{k_{1,\,cat\,3}} \\ z_{k_{2,\,cat\,3}} \end{bmatrix} = \begin{bmatrix} 1 \cdot 1 & 0 \cdot 0 \\ 0 \cdot 0 & \frac{1}{2} \cdot 1 \end{bmatrix} \cdot \begin{bmatrix} z_{f_{1,\,cat\,3}} \\ z_{f_{2,\,cat\,3}} \end{bmatrix} \tag{23}$$

If the relationship is 1:n, one function can be related to move than different components. This situation is shown in **Table 4**, if it is read from the top down, i.e. from the point of view of the functions. In the reverse direction each component is related to a single or to several identical components.

Table 4: Table of combinations for the fictive 1:n-relationship from figure 4

	Function f_i	
Comp. k_j	1	2
1	1	0
2	1	0
3	0	1
4	0	1
4	0	1

The 1:n relationship is recognisable in the matrix from the fact that, in $C_{(I,J)}$ each row and in $H_{(I,J)}$ each column, contains at least two fields which are not equal to zero. The situation of a 1:n relationship is demonstrated for the example depicted in Fig.4 by Equations 24 and 25.

$$(24)\quad \begin{bmatrix} f_1 \\ f_2 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} k_1 \\ k_2 \\ k_3 \\ k_4 \end{bmatrix}$$

$$(25)\quad \begin{bmatrix} k_1 \\ k_2 \\ k_3 \\ k_4 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \end{bmatrix}$$

Another characteristic of this type of relation is that the a_{ij} share-of-costs factors can only have the value “1” or “0”, exactly as in the case of a 1:1 relationship (see Equation 26), as each component is only related to one function (or several identical ones).In contrast, the b_{ij} share-of-costs factor can assume any value between “0” and “1” and is represented as a formulaic symbol in Equation 27.

$$(26)\quad \begin{bmatrix} z_{f_{1,cat\,3}} \\ z_{f_{2,cat\,3}} \end{bmatrix} = \begin{bmatrix} 1\cdot 1 & 1\cdot 1 & 0\cdot 0 & 0\cdot 0 \\ 0\cdot 0 & 0\cdot 0 & 1\cdot 1 & 2\cdot 1 \end{bmatrix} \cdot \begin{bmatrix} z_{k_{1,cat\,3}} \\ z_{k_{2,cat\,3}} \\ z_{k_{3,cat\,3}} \\ z_{k_{4,cat\,3}} \end{bmatrix}$$

$$(27)\quad \begin{bmatrix} z_{k_{1,cat\,3}} \\ z_{k_{2,cat\,3}} \\ z_{k_{3,cat\,3}} \\ z_{k_{4,cat\,3}} \end{bmatrix} = \begin{bmatrix} 1\cdot b_{11} & 0\cdot 0 \\ 1\cdot b_{12} & 0\cdot 0 \\ 0\cdot 0 & 1\cdot b_{23} \\ 0\cdot 0 & \frac{1}{2}\cdot b_{24} \end{bmatrix} \cdot \begin{bmatrix} z_{f_{1,cat\,3}} \\ z_{f_{2,cat\,3}} \end{bmatrix}$$

If the relations is an m:1 type, one component can stand in a relationship with a number of different functions. On the other hand, one function relates only to a single component (or to several identical ones - see **Table 5**).

Table 5: Table of combinations for the fictive m:1-relationship from figure 4

	Function f_i				
Comp. k_j	1	2	3	4	4
1	1	1	0	0	0
2	0	0	1	1	1

From Equations 28 and 29 it can be seen that a m: 1 relationship is present in that in each column of $C_{(I,J)}$ and each row of $H_{(I,J)}$, at least two fields are not equal to zero.

$$(28)\quad \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 0 \\ 1 & 0 \\ 0 & 1 \\ 0 & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} k_1 \\ k_2 \end{bmatrix}$$

$$(29)\quad \begin{bmatrix} k_1 \\ k_2 \end{bmatrix} \rightarrow \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 2 \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \end{bmatrix}$$

In this case, that of the m:l relationship, the b_{ij} share-of-costs factors can only assume the values “1” or “0” (see equation 31), but the a_{ij} share-of-costs b_{ij} will be any value from “0” to “1” (shown in Equation 30).

$$(30)\quad \begin{bmatrix} z_{f_{1,\,cat\,3}} \\ z_{f_{2,\,cat\,3}} \\ z_{f_{3,\,cat\,3}} \\ z_{f_{4,\,cat\,3}} \end{bmatrix} = \begin{bmatrix} 1 \cdot a_{11} & 0 \cdot 0 \\ 1 \cdot a_{21} & 0 \cdot 0 \\ 0 \cdot 0 & 1 \cdot a_{32} \\ 0 \cdot 0 & \frac{1}{2} \cdot a_{42} \end{bmatrix} \cdot \begin{bmatrix} z_{k_{1,\,cat\,3}} \\ z_{k_{2,\,cat\,3}} \end{bmatrix}$$

$$(31)\quad \begin{bmatrix} z_{k_{1,\,cat\,3}} \\ z_{k_{2,\,cat\,3}} \end{bmatrix} = \begin{bmatrix} 1 \cdot 1 & 1 \cdot 1 & 0 \cdot 0 & 0 \cdot 0 \\ 0 \cdot 0 & 0 \cdot 0 & 1 \cdot 1 & 2 \cdot 1 \end{bmatrix} \cdot \begin{bmatrix} z_{f_{1,\,cat\,3}} \\ z_{f_{2,\,cat\,3}} \\ z_{f_{3,\,cat\,3}} \\ z_{f_{4,\,cat\,3}} \end{bmatrix}$$

2.2 Estimation of the costs of Category One

Fig. 5 shows an excerpt from an m:n relationship in which the costs of category which require estimation are entered.

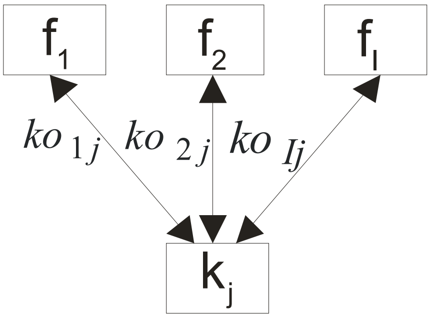

Fig. 5: Arrow diagram to show the Category One costs (for a particular component j) which are directly attributable to the functions and require estimation

The following three questions, which express the internal logic of the estimation process, must be answered in connection with this estimation:

Question 1: What resources are consumed for the production of components j ?

- Answer: Resources *1...U* or *1...V* (see also the structure in **Fig. 6**).

Question 2: For what purpose are these components j required – i.e., indirectly, what are the resources required for?

- Answer: To fulfil the functions *1...I.*

Question 3: By how much will the consumption of the resources v, be reduced if function f_i fails to be fulfilled?

- Answer: By Δq (see also the structure in Fig. 6).

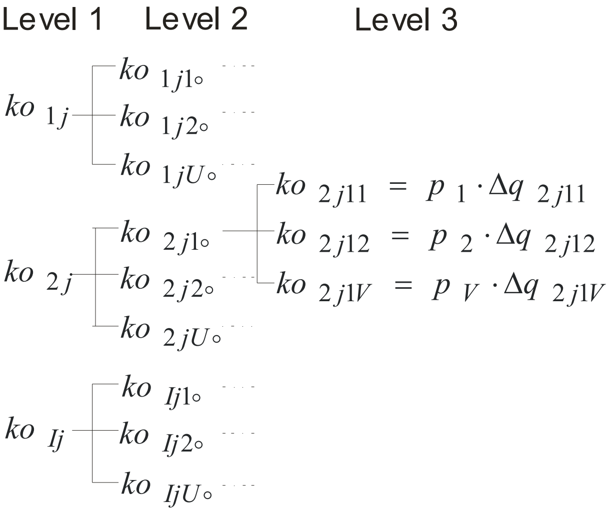

Fig. 6: Structure of the estimation task in respect of Category One costs for a particular component j

The structure of the estimation task has three levels and is divided into three structurally identical branches. Each branch shows the structure of the resources that are used to produce the components *j*, and is concerned with a function *i*, which relates to the component.

Level one contains the costs of Category One ko_{ij} for all functions ko_{ij} standing in relation to the components. On level Two the types of costs caused by the prediction of the components are contained, grouped into categories. Such cost categories are, for example, materials costs or manufacturing costs (ref. Monden 1995, pp. 239). As this costs structure is likely to be too complex for many uses, costs categories should be further differentiated on Level Three.

There, the cost categories such as materials costs are broken down further, e.g. “cost of copper”. The estimated figures will be combined for each category. On Level Three the type of cost will also be split up into its “quantity” and “price per item” elements. In this manner, Level Three of the cost estimation constitutes a mechanism whereby a change Δq in the quantity of a resource (copper, for example), is estimated if a function is deleted which had a relationship with a particular component.

2.3 Calculation and break down of function costs

As can be seen from the structure of the estimation task (see Figure 6), changes in quality are estimated on the lowest level (see Level Three). These reductions increases are multiplied by the price for the relevant resource, which results in the cost modification designated by the formulaic symbol ko_{ijuv}. If these changes in cost are added together for each resource *u* (see Equation 32) used in producing the component *j* (see Level Two), the result is the component costs in category for the component; in relation to function *i*; and this result can be expressed either as ko_{ij} or as $z_{k_{j,\,cat\,1}}$ (see Equation 8 in Table 2).

$$(32)\quad ko_{iju\circ} = \sum_{v=1}^{V} ko_{ijuv}$$

Using the $C_{(I,J)}$ matrix produced on analysis of the m:n relationship, the functions costs of Category Two can be calculated on the basis of Equations 9 or 10.

To determine the function costs for Category Three, it is first necessary to calculate the share-of-costs *a* factors – which can be done using Equation 18. The a_{ij} share-of-costs factors for a particular component must add up to 1 (one) – see Equation 33. This is necessary, as 100% of the costs of any component should be used for the calculation of function costs.

$$(33)\quad \sum_{i=1}^{I} a_{ij} = 1$$

To calculate the share-of-costs factors, the Category One component costs $z_{k_{j,\,cat\,1}}$, obtained from the estimations, are required, as are the Category Two component costs $z_{k_{j,\,cat\,2}}$. Then with the aid of the share-of-costs *a* factors, the Category Three function costs $z_{f_{i,\,cat\,3}}$ are determined by applying Equations 13 or 14.

Category Four function costs $z_{f_{i,\,cat\,4}}$ can ensue according to Equation 17. Category Three costs of the components $z_{k_{j,\,cat\,3}} \cdot c_{ij}$ with a relation to the function are entered in this Equation, together with the Category Two component costs $z_{k_{j,\,cat\,2}}$ and the Category Two function costs. The Category Two component costs will have had to be calculated before having using Equations 11 or 12.

For the target costs split, the function costs have to be broken down and assigned to the individual components of the product (ref. Ansari/Bell 1997, p. 56). This splitting of the function costs is achieved in essence with the assistance of the share-of-costs *b* factor, which can be determined on the basis of the Category Three functions and components costs ($z_{f_{i,\,cat\,3}}$ and $z_{k_{j,\,cat\,3}}$) together with the share-of-costs a factors (see Equation 19).

As 100% of the costs of a function are to be assigned to the components standing in relationship with that function, all b_{ij}-values for the components added up must always be equal to 1 (one), see Equation 34.

$$(34) \quad \sum_{j=1}^{J} b_{ij} = 1$$

Using the share-of-costs *b* factors, the target function costs can be calculated from either Equation 1 or Equation 16.

2.4 Importance of the different categories of function costs

If there is a decision to eliminate a function from a product as currently configured, the Category Two function costs are relevant to that decision, as they are the costs which are deleted if the relevant function no longer has to be fulfilled (see **Fig. 7**). This category of function cost is thus particularly important if products are being reengineered, to instance in the context of a Value Analysis (ref. Miles 1961 and Sakurai 1996, pp. 55) or if the design is being adapted.

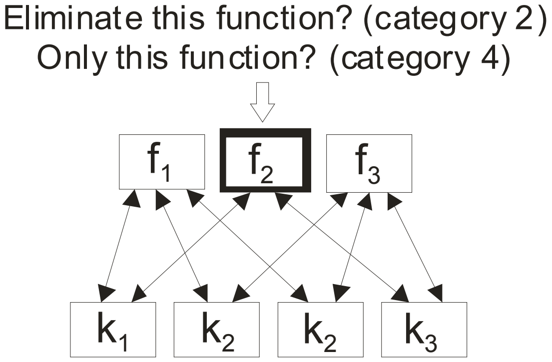

Fig. 7: Significance of the Category Two and Four function costs for cost-oriented design of engineered products

The Category Three functions costs are significant in the early stages of engineering design, when the product configuration is settled on. It is they which show the part played by function costs f_i in the product costs *Z*, and they can be compared with the target function costs. The latter comprise the Category Two function costs plus a fundamental element that is not generated by an individual function but does arise for the product as a whole. Together these are the costs caused by the function within the context of the particular configuration of functions. Target Costing usually works with Category Three function costs, as the design and the costs are required to meet the market sectors specifications in the medium term.

Category Four function costs can be interpreted as marginal costs in relation to the “zero situation”, i.e. the position where no function of the product has yet been fulfilled. If a market sector or a particular potential customer only requests one function, the costs for that function will be in the amount of Category Four (see Figure 7). If the product is to fulfil more than one function, but yet not all those originally proposed, further categories of function costs must be defined as a basis for that type of decision.

3 Functions costs for a car park management system

3.1 Analysing the functions and components of the car park system

A car park management system basically consists of two areas geographically separate from one another: the central management office and the parking space itself. In the latter, the pay-and-display machines are erected for the customers to use. The user puts money into the machine and receives a ticket, which is usually to be left on show in the car. Small systems will have up to 50 machines, major ones may well consist of hundreds.

The central office monitors and regulates the car park charging system. Essential information must be stored in the machines and transmitted to the office. There are various computer programs which can be used to perform or improve the monitoring and regulation.

In the case studied, the system was relatively small, in that it consisted of 15 pay-and-display machines. This size of system can be managed from a personal computer and its peripherals (monitor, printer, DFÜ-PC point, tape drive) - see **Fig. 8**.

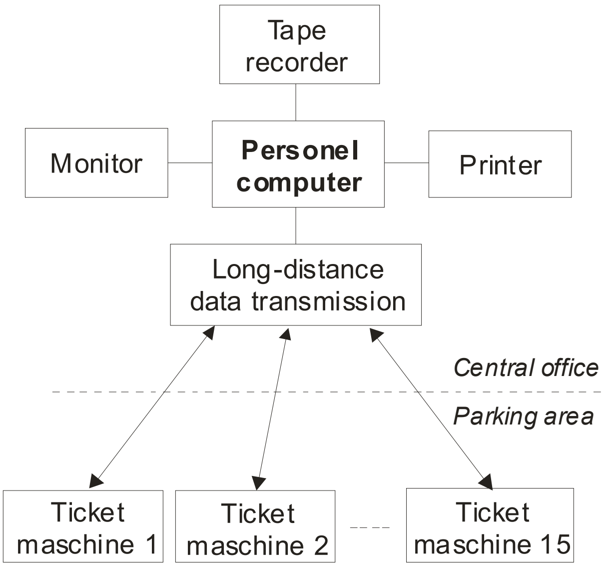

Fig. 8: Format of the car park management system, consisting of a central office with a personal computer, plus 15 pay-and-display machines on the parking area

The machine provides the tickets for the parking space being managed. The user can insert coins as the means of selecting a period (up to a programmed maximum time). The amount of time paid for, when it ends, and how much has been paid as parking fee will be shown on the display after each coin is inserted.

As the machine has a modular construction, its functions can be varied to suit the operator. It can be set up, for instance, with the option of card payment instead of or in addition to cash. Likewise, alternative display modules and other options are available. The number of possible variations is wide, but not every component is required for each version of the machine.

As the share-of-costs for the different possible components of the car park management system varies greatly as a proportion of the cost of the whole system, it makes commercial sense to differentiate between the components that have a significant effect on costs and those that do not. ABC analysis is of assistance here. To select the components with high relevance to cost, there must first be a ready-configured version of the management system for which components costs can be determined. As soon as the structure of entire system has thus been laid down, cost analysis can start.

Table 6: Results of the ABC-analysis for the components of the car parking system

No.	Description	Purchased parts in $	Manufacturing in $	1 complete machine in $	15 machines in $	Costs (cumulated)	Fraction in %
1	Basic format	749	172	921	13,815	13,815	24.50
2	Coin processing	889	119	1008	15,120	28,935	51.30
3	Data transmission	433	91	524	7,860	36,795	65.30
4	Hardware	-	-	-	5,808	42,603	75.60
5	Energy supply	294	47	341	5,115	47,718	84.60
6	Printer	214	6	220	3,300	51,018	90.50
7	Software	-	-	-	1,380	52,398	92.90

For reasons of economy, it is valuable only to include the significantly costly components in the determination of function costs. In the study, an ABC analysis was carried out, with the outcome shown in Table 6. The seven most expensive components were then included in the investigation, ranging from 1 (basic format) to 7 (management software). As these seven covered 92.9% of the costs of the car park management system, they were deemed sufficient for the study.

Table 7: Functions of the car parking system, expressed as noun and verb

No.	Functions	
	Verb	Noun
1	inform	user
2	receive	parking fee
3	fix	parking fee
4	confirm	payment
5	label	car
6	supervise	functionality
7	supervise	money transfer
8	protect	system

Analysing the function structure (as a function tree) starts with an analysis of the purpose of the system in question. Expressed in complex, abstract terms this is the commercial management of the parking space. The overall function can be subdivided into subordinate functions which reflect the structural components of the system. Further subdivision is accompanied by reduction in complexity: i.e., the complex overall function is broken down into less complex subdivisions (ref. Hubka/Eder 1984, pp. 72 and Akiyama 1991, p. 50).

As calculating the costs for absolutely all the sub-functions would be uneconomic, a degree of detail has to be selected which is adequate to cost-oriented product design, by excluding functions with low complexity. In Table 7 there is a summary of the functions which require their cost to be analysed. They are stated in the conventional (ref. Akiyama 1991, p. 41) form of noun and verb.

There is an m:n relationship between the functions and the components in this product, and it can be depicted in a combination table which describes the relation between the elements of two sets, in this case the set of functions and that of components (see Table 8).

Table 8: Table of combinations, indicating the relations between the functions and components of the car parking system

			Functions f_i							
	No.	k_j	1	2	3	4	5	6	7	8
Components	1...15	1	1	1	1	1	1	1	1	1
	16...30	2		1	1				1	1
	31...45	3						1	1	1
	46	4						1	1	1
	47...61	5		1	1	1	1	1	1	1
	62...77	6				1	1		1	
	78	7						1	1	1

There are eight elements contained in the function set and 78 in the components set; of this set, components nos. 1, 2, 3, 5 and 6 are contained 15 times in the car park management system in identical form. The figures “1” entered in Table 8 indicate a relation between the relevant component and function. If there is no entry in the table, the elements do not have a relation to one another.

It is clearer to show the relation as a matrix if the situation is one where certain components or functions recur in identical from, as in the present example. If a component or a function only appears singly, the matrix will depict the combination table presented as Table 8 with either a “1” (relation exists) or an “0” (no relation exists). Reading the combination table from the top down, the matrix is obtained for the “bottom-up” situation - function costs determined on the basis of component costs, as shown in Equation 35. For the car park system and the bottom-up situation, the proportion of the cost of a component (e.g. component no. 1) assignable to a function (e.g. function no. 1) is multiplied on the number if identical components that are related to that function (15 in the example). What is meant is that the 15 components of type 1 are all involved in the fulfilment of the function no. 1.

$$\begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \\ f_7 \\ f_8 \end{bmatrix} \rightarrow \begin{bmatrix} 15 & 0 & 0 & 0 & 0 & 0 & 0 \\ 15 & 15 & 0 & 0 & 15 & 0 & 0 \\ 15 & 15 & 0 & 0 & 15 & 0 & 0 \\ 15 & 0 & 0 & 0 & 15 & 15 & 0 \\ 15 & 0 & 0 & 0 & 15 & 15 & 0 \\ 15 & 0 & 15 & 1 & 15 & 0 & 1 \\ 15 & 15 & 15 & 1 & 15 & 15 & 1 \\ 15 & 15 & 15 & 1 & 15 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} k_1 \\ k_2 \\ k_3 \\ k_4 \\ k_5 \\ k_6 \\ k_7 \end{bmatrix} \tag{35}$$

On the other hand, if the combination table is read off from left to right, the situation is top-down and is described by Equation 36: the function costs are broken down and assigned. In this case, the proportion of the cost of a function (e.g. function no. 1), which falls on to the components standing relation to the function (e.g. component no. 1) must be divided by the number of identical components which have that relation (15 in the example). This means that only 1/15 of the costs of function 1 can be attributed to a single no. 1 type component.

$$\begin{bmatrix} k_1 \\ k_2 \\ k_3 \\ k_4 \\ k_5 \\ k_6 \\ k_7 \end{bmatrix} \rightarrow \begin{bmatrix} \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} \\ 0 & \frac{1}{15} & \frac{1}{15} & 0 & 0 & 0 & \frac{1}{15} & \frac{1}{15} \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} & \frac{1}{15} \\ 0 & 0 & 0 & \frac{1}{15} & \frac{1}{15} & 0 & \frac{1}{15} & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \end{bmatrix} \cdot \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \\ f_7 \\ f_8 \end{bmatrix} \tag{36}$$

3.2 Estimation of the costs of Category One

The structure of the estimation test as it can be constructed for the car park system is shown in**Table 9**. The component “coin processing” (no. 2 in the system) is in a relationship to functions 2, 3, 7 and 8 (see column A). Costs arise in connection with the installation of coin processing in the system: costs for purchased parts and their assembly (see column B). The amount of these costs in the event is entered in column C and their estimated value in Column D. The estimator gives the value at which the component costs alter.

Table 9: Structure of the estimation task for the coin processing unit as a representative component

A	B		C	D
Function	Cost category		Initial base in $	Estimated value in $
	Formula	Description		
f_2	ko_{221}	purchase	889	427
	ko_{222}	manufacturing	119	70
f_3	ko_{321}	purchase	889	872
	ko_{322}	manufacturing	119	115
f_7	ko_{721}	purchase	889	527
	ko_{722}	manufacturing	119	111
f_8	ko_{821}	purchase	889	880
	ko_{822}	manufacturing	119	111

It is a vital precondition of proper estimations that the estimator is familiar with the construction of the components and the content of the functions of the car park management system. Only with such comprehensive knowledge (concerning for example, coin processing) can a certain judgment be made as to the influence of the functions on the particular component. Not only is this knowledge of the construction of the components and the resultant costs of purchased parts necessary, but also experience of manufacture and assembly in the particular field, to aid understanding of the manufacturing costs.

Estimation on a secure basis also requires other knowledge besides that of the construction and manufacturing process. Knowledge of the content of the individual functions is indispensable, and such is only to be obtained with good insight into that content (e.g., what is meant under function no.2, “receive parking fee”). It is helpful to the estimator if the overall structure of the functions is laid out before him or her, with relevant notes and possible highlighting. Then the function in question can be viewed from the standpoint of how it interacts with other functions.

The estimator, must, furthermore, be able to imagine a virtual component design[5] in which these is no fulfilment of the functions whatsoever. He or she must not only be capable of imagining the construction of the components to arrive at estimated costs for purchased parts, but also to arrive at the estimated manufacturing and assembly costs which would arise from the virtual component design as manufacturing processes and times. The qualifications necessary for the estimator can be laid down on the basis of the specifications defined for the system. Such qualifications would generally include the overall personal skills, abilities and knowledge which they possess to enable them to perform a specific task. In this case the task is the estimation task, and the estimator must be equal to it.

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[5] “A virtual component design” here means the estimator’s mental construct of “ideal” components.

3.3 Calculation and break down of function costs

The data for component no. 2 were obtained in the study from a questionnaire completed by the way of example (see Table 9). This component costs (Category One) to be calculated according to equation 8.

Taking component no. 2 as an example direct component costs for the functions (Category One) are the sum of the differences between the starting point and the estimated figures for the two types of cost: purchased parts and manufacture. The costs come to $ko_{22} = 511\,\$$ for function no.2, and to $ko_{32} = 21\,\$$ for function no. 3. In case of function 7 and 8 they come to $ko_{72} = 370\,\$$ and $ko_{82} = 17\,\$$.

Equation 37 takes component no. 2 as an example and shows how the Category Two component costs can be calculated with the aid of Equations 11 or 12. The Category One, or directly attributable, costs for component no. 2 are added together as they are calculated for all functions to which the component is related.

$$(37)\quad z_{k_{2,\,cat\,2}} = \begin{bmatrix} 0 & 15 & 15 & 0 & 0 & 0 & 15 & 15 \end{bmatrix} \cdot \begin{bmatrix} 0 \\ 511 \\ 21 \\ 0 \\ 0 \\ 0 \\ 370 \\ 17 \end{bmatrix} = 13{,}785\,\$$$

Now function 3 may be taken as an example of how Category Two function costs are calculated: the equation is Equations 38 and it proceeds using Equations 9 or 10. The Category One costs of component no.2 in relation to function no.3 were determined as $ko_{32} = 21\,\$$. Given that component no. 2 is contained 15 times in the parking system, and that function no. 3 is related not only to component no. 2 but also to nos. 1 and 5, the Category Two the function costs come to $z_{f_{3,\,cat\,2}} = 1{,}770\,\$$.

$$(38)\quad z_{f_{3,\,cat\,2}} = \begin{bmatrix} 15 & 15 & 0 & 0 & 15 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} 65 \\ 21 \\ 0 \\ 0 \\ 32 \\ 0 \\ 0 \end{bmatrix} = 1{,}770\,\$$$

Category Three function costs can only be calculated if the share-of-costs factors have first been produced. The *a*-share-of-costs factors are determined using Equation 18: below, the calculation of the a_{32} factor is demonstrated in Equation 39. The share-of-costs factors are then entered into the matrix for the calculation of the Category Three function costs (see Equation 40).

(39) $$a_{32} = \frac{ko_{32} \cdot c_{32}}{z_{k_{2,\,cat\,2}}} = \frac{21\,\$ \cdot 15}{13{,}785\,\$} = 0.023$$

(40) $$\begin{bmatrix} 690 \\ 10{,}195 \\ 2{,}730 \\ 3{,}396 \\ 3{,}396 \\ 7{,}109 \\ 14{,}630 \\ 10{,}228 \end{bmatrix} = \begin{bmatrix} 15 \cdot 0.050 & 0 \cdot 0 & 0 \cdot 0 & 0 \cdot 0 & 0 \cdot 0 & 0 \cdot 0 & 0 \cdot 0 \\ 15 \cdot 0.037 & 15 \cdot 0.556 & 0 \cdot 0 & 0 \cdot 0 & 15 \cdot 0.250 & 0 \cdot 0 & 0 \cdot 0 \\ 15 \cdot 0.080 & 15 \cdot 0.023 & 0 \cdot 0 & 0 \cdot 0 & 15 \cdot 0.250 & 0 \cdot 0 & 0 \cdot 0 \\ 15 \cdot 0.074 & 0 \cdot 0 & 0 \cdot 0 & 0 \cdot 0 & 15 \cdot 0.250 & 15 \cdot 0.333 & 0 \cdot 0 \\ 15 \cdot 0.074 & 0 \cdot 0 & 0 \cdot 0 & 0 \cdot 0 & 15 \cdot 0.250 & 15 \cdot 0.333 & 0 \cdot 0 \\ 15 \cdot 0.050 & 0 \cdot 0 & 15 \cdot 0.500 & 1 \cdot 0.333 & 15 \cdot 0.000 & 0 \cdot 0 & 1 \cdot 0.400 \\ 15 \cdot 0.074 & 15 \cdot 0.403 & 15 \cdot 0.500 & 1 \cdot 0.333 & 15 \cdot 0.000 & 15 \cdot 0.333 & 1 \cdot 0.400 \\ 15 \cdot 0.561 & 15 \cdot 0.018 & 15 \cdot 0.000 & 1 \cdot 0.333 & 15 \cdot 0.000 & 0 \cdot 0 & 1 \cdot 0.200 \end{bmatrix} \cdot \begin{bmatrix} 921 \\ 1{,}008 \\ 524 \\ 5{,}808 \\ 341 \\ 220 \\ 1{,}380 \end{bmatrix}$$

By multiplying the column vector for the components costs by the matrix for the share-of-costs factors, the necessary vector for the function costs can be found. The sum of the costs for all the factors comes to 52.398 $ and is the actual cost of the entire car park management system. This sum is also that obtained (but for small variations from rounding up or down) when the costs of all 78 components are added together.

To calculate the Category Four functions costs for function no. 3 according to Equation 5 ($z_{k_{1,\,cat\,3}} = 921\,\$$, $z_{k_{2,\,cat\,3}} = 1{,}008\,\$$, $z_{k_{5,\,cat\,3}} = 341\,\$$) must first be multiplied by the number of these components ($c_{31}, c_{32}, c_{35} = 15$) which have a relation to function no.3.

The functions costs are the sum of the differences ($z_{k_{1,\,cat\,3}} \cdot c_{31} - z_{k_{1,\,cat\,2}} = 1{,}620\,\$$)

plus the Category Two function costs ($z_{k_{2,\,cat\,3}} \cdot c_{32} - z_{k_{2,\,cat\,2}} = 1{,}335\,\$$),

i.e. ($z_{k_{5,\,cat\,3}} \cdot c_{35} - z_{k_{5,\,cat\,2}} = 3{,}195\,\$$, $z_{f_{3,\,cat\,2}} = 1{,}770\,\$$).

To split the function costs, the *b* share-of-costs factors are required. Equation 41 shows how this is done, using the b_{32} as an example.

(41) $$b_{32} = \frac{z_{k_{2,\,cat\,3}} \cdot c_{32}}{z_{f_{3,\,cat\,3}}} \cdot \mathrm{a}_{32} = \frac{1{,}008\,\$ \cdot 15}{2{,}730\,\$} \cdot 0.023 = 0.127$$

The b_{ij}-share-of-costs factors and the function costs from equation 40 can now be entered in the matrix used to calculate the components costs (see Equation 42).

(42)

$$\begin{bmatrix} 921 \\ 1{,}008 \\ 524 \\ 5{,}808 \\ 341 \\ 220 \\ 1{,}380 \end{bmatrix} = \begin{bmatrix} \frac{1}{15}\cdot 1.000 & \frac{1}{15}\cdot 0.050 & \frac{1}{15}\cdot 0.405 & \frac{1}{15}\cdot 0.301 & \frac{1}{15}\cdot 0.301 & \frac{1}{15}\cdot 0.097 & \frac{1}{15}\cdot 0.070 & \frac{1}{15}\cdot 0.757 \\ 0\cdot 0 & \frac{1}{15}\cdot 0.825 & \frac{1}{15}\cdot 0.127 & 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & \frac{1}{15}\cdot 0.416 & \frac{1}{15}\cdot 0.027 \\ 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & \frac{1}{15}\cdot 0.553 & \frac{1}{15}\cdot 0.269 & \frac{1}{15}\cdot 0.000 \\ 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 1\cdot 0.272 & 1\cdot 0.132 & 1\cdot 0.190 \\ 0\cdot 0 & \frac{1}{15}\cdot 0.125 & \frac{1}{15}\cdot 0.468 & \frac{1}{15}\cdot 0.376 & \frac{1}{15}\cdot 0.376 & \frac{1}{15}\cdot 0.000 & \frac{1}{15}\cdot 0.000 & \frac{1}{15}\cdot 0.000 \\ 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & \frac{1}{15}\cdot 0.323 & \frac{1}{15}\cdot 0.323 & 0\cdot 0 & \frac{1}{15}\cdot 0.075 & 0\cdot 0 \\ 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 0\cdot 0 & 1\cdot 0.078 & 1\cdot 0.038 & 1\cdot 0.027 \end{bmatrix} \cdot \begin{bmatrix} 690 \\ 10{,}195 \\ 2{,}730 \\ 3{,}396 \\ 3{,}396 \\ 7{,}109 \\ 14{,}630 \\ 10{,}228 \end{bmatrix}$$

The components costs calculated in Equation 42 must agree with those from Table 6. The sum of 78 components comes to 52,398 $ and thus again reflects the overall costs of the system.

3.4 Importance of the different categories of function costs

The Category One costs are the costs applying to a single function and a single component. It follows that a single component no. 2 (coin processing) – though it must be remembered that there are 15 of this component in the system – can be calculated as being responsible for $z_{f_{3,\,cat\,1}} = ko_{32} = 21\,\$$ of function no. 3 (fix parking fees). Conversely, and this is of importance for function costs splitting, $z_{k_{2,\,cat\,1}} = ko_{32} = 21\,\$$ can also be broken down to function no. 3 for a single component no. 2.

It is, however, interesting from the point of new engineering design to ask how high the costs of function 3 (fix parking fees) are if the Category One costs of all 15 component no. 1`s associated with this function (which are basic format and energy supply) are added together. A decision can be made, in the context of a Value Analysis (for example), on the basis of these costs, $z_{f_{3,\,cat\,2}} = 1{,}770\,\$$, as to whether function no. 3 (fix parking fees) should actually be deleted from the car parking management system.

If it is being decided in the early design engineering stages whether to include function no. 3 (fix parking fees) in how the system is configured, the Category Three function costs of $z_{f_{3,\,cat\,3}} = 2{,}730\,\$$ are relevant. During Target Costing they can be compared with the function costs derived from market research and related to the customer benefit.

The question can, indeed, be asked how high the car park management costs are if solely the function no. 3 (fix parking fees) is to be fulfilled; that is, if all the other seven functions are to be eliminated. The Category Four costs for function no. 3 would come out at $z_{f_{3,\,cat\,4}} = 7{,}920\,\$$.

4 Conclusion

The question here addressed is how the calculated cost of consumption of all production factors relevant to the entire life cycle of a product can be allocated to individual product functions. A method with general validity has been developed to calculate such function costs.

Significant among the results obtained are the proposed solutions to the hitherto intransigent problems of function cost determination, which include thorough analysis of the m:n relationship between functions and components, a mathematical concept to describe the function costs in Categories One to Four, and presentation of the task involved in estimating directly attributable component costs (Category One).

Function cost splitting constitutes a further issue which is closely associated with functions costs determination and arises in association with Target Costing. As the only question addressed in calculating and assigning costs between component and functions is whether they actually cause the cost, function cost splitting is at heart function cost determination. This being recognised, the question arises whether there is any target cost splitting going on at all when function costs are split. As the splitting of target costs, at least those derived from market research, is only logical if it fulfils the cost/benefit principle, the answer must be no.

The aim of a function costs determination method has been formulated thus: it must be generally valid, truly represent cause and effect, and be cross-checkable internally and usable in practice.

To assign component costs to functions, it is necessary to have a formula which does reflect what causes what. To act as a basis for the formula, an actual figure is required, the directly attributable component costs (here called Category One component costs) produced by the direct influence the function has on the component. If this is the case, a high degree of reliability for the cause-and-effect link is ensured.

Cross-checkability is achieved when different people can produce the same or similar results. This is an issue, if for no other reason, because there are subjective elements contained not only in function cost analysis, but already in the function models (particularly the derivation of product functions). By describing in detail the process of function costs analysis, the amount of free play allowed the investigating staff can be fixed from the beginning, and the effects of subjectivity limited. By thorough pursuit of the analysis of the m:n relation and the detailed description of the estimation task, the work described in this paper has made a significant step in the necessary direction.

To date, the subject of function cost analysis has been dealt with only with the tools of cost-oriented engineering design, such as Value Analysis, Target Costing or Quotation Calculations. Although the present work offers its approach to function costs analysis chiefly as a service to cost-oriented design in general and only secondarily to its currently-applied instruments, it may well also serve a useful purpose in the resolution of the overall issues currently confronting those instruments.

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