Cost Planning for Functions and Components in engineering design – theory and application

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Abstract: Planning of life-cycle costs is an essential requirement for the cost-oriented design of customised engineering products. The planned costs need to be broken down and allocated to the product's (sub)divisions, or functions and components. The paper presents the theoretical background for "guesstimation" - an estimation expressed as a result of subjective perceptions and cognitions - of the weightings which are necessary for costs to be appropriately assigned. The weightings help planners to state how functions may cause costs in components, and vice versa. The paper also describes an application in Brazilian industry and indicates further research opportunities.

Keywords: Function costs, cost estimation, target costing, value engineering.

1. Introduction

1.1 The target costing process

The costs of functions and components must be established if one is applying such cost-oriented approaches in product design as Target Costing and Value Engineering. In Target Costing, one starts by deriving the product price from the potential market. This product price will be valid for a demarcated market segment, a given volume of sales and a specific level of quality (see Figure 1). Subtracting the planned profit margin from the market price gives to the Allowable Costs of the engineering product. These costs can be allocated to the product's functions by using Conjoint Analysis. This will be further described in chapter 2.1.

If the future product is to be profitable, the Allowable Costs thus computed may not exceed the costs for which it will actually be possible to produce the product. The determination of those actual costs, the Drifting Costs, usually begins with the costs of components either manufactured at the production site or supplied by subcontractors. Here there is the problem of how to allocate costs from the components to the functions. Because of the m:n relationship (explained in chapter 2.2 and 2.3) between functions and components, there is no simple logical basis available to assist in this allocation.

After the Drifting Costs (both for functions and for the whole product) have been determined, they can be compared with the Allowable Costs. As the Drifting Costs are usually higher than the Allowable Costs, negotiations are carried out among the departments involved (engineering design, production planning, cost accounting) to arrive at the Target Costs for the whole product and for its functions. The Target Costs have to be broken down to Target Costs for the various components. Again, the complex, m:n, relation gives rise to difficulty. A clear basis for the cost assignment has yet to be developed. What follows is a contribution.

1.2 Embraco S.A. and the compressor EM Brazil

A software tool to be described in chapter 1.3 was applied experimentally at Empresa Brasileira de Compressores S.A. (Embraco), a company founded in 1971 in Joinville, Brazil and currently biggest manufacturer of hermetic compressors for refrigeration solutions, worldwide. Embraco has factories in North America, Europe and Asia, with more than 9000 employees overall. The compressors come as many models with innumerable variations because they need to be tailor-made for the customer or the particular refrigerator or freezer.

The compressor considered for the purposes of this paper, and described in more detail in chapter 2.5, belongs to the type EM Brazil (see Figure 2) and consists of five main components:

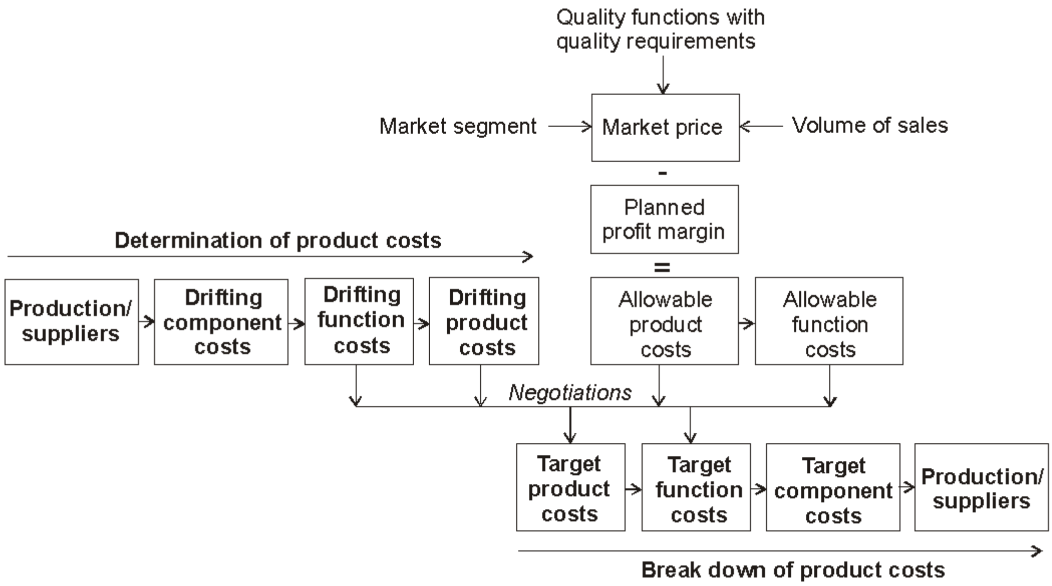


Figure 1 – The Target Costing Process

♦ the housing

♦ the electrical part (power supply and the thermal protector)

♦ the motor

♦ the mechanical part (for transmission and compression of the refrigerant)

♦ the valve behind the compression chamber.

1.3 The software tool developed

To assist in the allocation of costs between functions and components (as used in Target Costing and Value Engineering), a software tool based on Microsoft Excel has been developed. The application is controlled by Visual Basic for Applications (VBA) routines and there are dialog boxes for the input of data.

Figure 2 – The Compressor EM Brazil

The tool not only allows the calculation of costs, but also computation of the necessary weightings from the guesswork of a number of different estimators.

2. Assignment of Costs to Functions and Components

2.1 From product costs to function costs

Cost assignment must always run parallel to the design process [see Schneider/Dittrich 2000, pp. 106-108]. The first step is to calculate the Allowable Coats {Z} from the market price and then break them down across the product's functions. For the computation of the function costs, as shown in equation 3, weightings are necessary to describe the importance of a function to the customer. Conjoint Analysis is a useful standard approach for the determination of these g_j-values [see Green/Srinivasan 1990 and Voeth 1999].

$$\begin{bmatrix} F_1 \\ F_2 \\ F_r \end{bmatrix} = Z \cdot \begin{bmatrix} g_1 \\ g_2 \\ g_r \end{bmatrix} \quad , \quad \sum_{j=1}^{r} g_j = 1 \qquad (3,4)$$

Assigning 100% of the Allowable Costs to the product's functions (see equation 4), is effectively normalising the weightings g_j as (the number) 1.

2.2 Possible relations between functions and components

For product planning and for the early (conceptual design) phases of the design process, the potential costs of each function need to be estimated from the costs of the necessary components. Later (in the embodiment design phase), the target costs need to be broken down and assigned to the components according to the functions [see Schweitzer/ Küpper 1998, pp. 667-670; Tanaka/ Yoshikawa/Innes/Mitchell 1995, pp. 52-54 and Tanaka 1989]. Deciding how to allocate costs – more in the component area, less in the functional, or vice versa – is problematic in both directions.

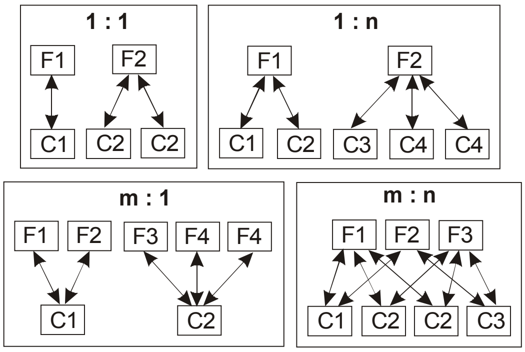


Figure 3 – Possible relations between functions and components (see Schlink/Schneider/Höhne 2001a)

A product can be modelled as a structure of functions and a related structure of components. The level of complexity for both structures must be defined for the relationship to be described and a particular set of functions and components to be delimited [see also Tanaka 1992, p. 145].

The 1:1 relation is the simplest and clearest relationship between components and functions, where one function is realized by one particular or many identical components. In the other direction, one component fulfils one particular or a number of identical functions (see Figure 3). In the case of a 1:n relation, a function is realised by at least two different components. The m:1 relations present the opposite problem. One component fulfils at least two different functions. In the most complex and unclear case, the m:n relation, both are possible: one function can be realised by many components and one component can fulfil many functions. Usually the component and the functions of an engineering product will require modelling as connected by an m:n relationship.

2.3 The m:n relationship

The m:n relationship can be formulated in matrix equations as in the equations 5 to 8. $\{F_j\}$ represents the costs of a particular function $\{j\}$; the $\{a_{jk}\}$ value stands for the fraction of costs of component $\{k\}$ that is caused by function $\{j\}$; and $\{c_{jk}\}$ identifies the number of identical components $\{k\}$ fulfilling (at least in part) the function $\{j\}$. Table 1 makes the nomenclature clear: weightings $\{a\}$ have indices $\{j\}$ and $\{k\}$.

Table 1 – The indices of the a_{jk}-value

a_{jk}	Range
Function $\{j\}$	$\{1 \ldots r\}$
Component $\{k\}$	$\{1 \ldots s\}$

Equation 5 shows the general calculation of function costs for the case of $\{r\}$ functions and $\{s\}$ components. Equation 6 applies this matrix for the m:n relation displayed in Figure 3.

$$\begin{bmatrix} F_1 \\ F_2 \\ F_r \end{bmatrix} = \begin{bmatrix} c_{11} \cdot a_{11} & c_{12} \cdot a_{12} & c_{1s} \cdot a_{1s} \\ c_{21} \cdot a_{21} & c_{22} \cdot a_{22} & c_{2s} \cdot a_{2s} \\ c_{r1} \cdot a_{r1} & c_{r2} \cdot a_{r2} & c_{rs} \cdot a_{rs} \end{bmatrix} \cdot \begin{bmatrix} C_1 \\ C_2 \\ C_s \end{bmatrix} \qquad (5)$$

$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} = \begin{bmatrix} 1 \cdot a_{11} & 2 \cdot a_{12} & 0 \cdot 0 \\ 1 \cdot a_{21} & 0 \cdot 0 & 1 \cdot a_{23} \\ 0 \cdot 0 & 2 \cdot a_{32} & 1 \cdot a_{33} \end{bmatrix} \cdot \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} \qquad (6)$$

The calculation of component costs from function costs is generally shown in equation 7. $\{C_k\}$ represents the costs of a particular component $\{k\}$; the $\{b_{jk}\}$ value stands for the fraction of costs of function $\{j\}$ that is generated by the component $\{k\}$; $\{f_{jk}\}$ gives the number of identical functions $\{j\}$ that are realized (at least in fraction) by the component $\{k\}$. The equation 8 shows the application of this calculation to the m:n relation in Figure 3. The indices, this time for the weightings $\{b\}$, are clarified in Table 2.

Table 2 – The indices of the b_{jk}-value

b_{jk}	Range
Function $\{j\}$	$\{1 \ldots r\}$
Component $\{k\}$	$\{1 \ldots s\}$

$$\begin{bmatrix} C_1 \\ C_2 \\ C_s \end{bmatrix} = \begin{bmatrix} f_{11} \cdot b_{11} & f_{21} \cdot b_{21} & f_{r1} \cdot b_{r1} \\ f_{12} \cdot b_{12} & f_{22} \cdot b_{22} & f_{r2} \cdot b_{r2} \\ f_{1s} \cdot b_{1s} & f_{2s} \cdot b_{2s} & f_{rs} \cdot b_{rs} \end{bmatrix} \cdot \begin{bmatrix} F_1 \\ F_2 \\ F_r \end{bmatrix} \qquad (7)$$

$$\begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} = \begin{bmatrix} 1 \cdot b_{11} & 1 \cdot b_{21} & 0 \cdot 0 \\ 0{,}5 \cdot b_{12} & 0 \cdot 0 & 0{,}5 \cdot b_{32} \\ 0 \cdot 0 & 1 \cdot b_{23} & 1 \cdot b_{33} \end{bmatrix} \cdot \begin{bmatrix} F_1 \\ F_2 \\ F_3 \end{bmatrix} \qquad (8)$$

As mentioned above, there is no logical (technical or economic) relationship between the components and functions of an engineering product. Therefore, one is obliged to use a “guesstimate” of the weightings $\{a_{jk}\}$ and $\{b_{jk}\}$ to assign the costs across the two structures

2.4 Conversion of the a_{jk} into b_{jk} weightings

It is interesting to ask whether $\{a_{jk}\}$ weightings can be computed from the $\{b_{jk}\}$ weightings and vice versa. As the following example indicates, this is usually not the case.

A matrix can only be inverted when it is of the quadratic type and its coefficient of determination is not equal to zero.

For the two matrixes (A and B) from equation 5 and 7 to be invertible in this sense, then the A matrix must be equal to the inverted B matrix and vice versa. But, as equation 9 shows, the A matrix multiplied by its inverted matrix, is equal to the identity matrix {I}.

$$A \cdot A^{-1} = A \cdot B = I \qquad (9)$$

The elements of the matrixes A, A^{-1}, B, B^{-1} must be in the range between 0 and 1, because only positive costs will be allocated between components and functions. Hence the conditions are only fulfilled if the A matrix and the B matrix are the identity matrix {I} or the mirrored identity matrix (see equations 10 and 11). Here the $\{a_{jk}\}$ weightings are elements of the A matrix and the $\{b_{jk}\}$ weightings are elements of the A^{-1} matrix with the necessary requirement of $0 \le a_{jk}, b_{jk} \le 1$.

$$\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \qquad (10)$$

$$\begin{aligned} a_{11} \cdot b_{11} + a_{12} \cdot b_{12} &= 1 \\ a_{11} \cdot b_{12} + a_{12} \cdot b_{22} &= 0 \\ a_{21} \cdot b_{11} + a_{22} \cdot b_{12} &= 0 \\ a_{21} \cdot b_{12} + a_{22} \cdot b_{22} &= 1 \end{aligned} \qquad (11)$$

2.5 Relations between functions and components of the EM Brazil

Returning to the EM Brazil compressor and the relationships between its functions and components, one finds that the product requires analysing according to the overall and sub-functions it fulfils and also according to its components. As shown in Table 3, the compressor can be subdivided into many assemblies and subassemblies, each indicated as $\{AS_{kx}\}$.

Table 3 – Components of the compressor (EM Brazil)

No. of assembly or sub-assembly			**Name**
C_1	AS_1		Housing
		AS_{11}	Compressor body
		AS_{12}	Compressor cover
C_2	AS_2		Power supply and thermal protector
		AS_{21}	Thermal protector
		AS_{22}	Relay or PTC
		AS_{23}	Relay housing
	AS_3		Motor
C_3		AS_{31}	Rotor
C_4		AS_{32}	Stator
	AS_4		Mechanics
C_5		AS_{41}	Oil pump
C_6		AS_{42}	Crank shaft
C_7		AS_{43}	Crank case
C_8		AS_{44}	Piston complete
C_9		AS_{45}	Oil
	AS_5		Valve
C_{10}		AS_{51}	Gaskets and covers
C_{11}		AS_{52}	Valve parts
C_{12}		AS_{53}	Suction chamber
C_{13}		AS_{54}	Discharge tube

On reviewing the costs of components, it is possible to select 13 as being in each case responsible for an adequate amount of costs. Their structure is displayed in Figure 4.

Turning to functions, one may subdivide the overall function of the compressor into many sub-functions, indicated by function areas $\{FA_{jx}\}$ in Table 4.

The functions $\{F_j\}$, which are the most important ones to the customer, happen in this case also to be 13 in number. The structure of these 13 functions is visualised in Figure 5.

Table 4 – Functions and sub-functions of the compressor (EM Brazil)

No. of level 1, 2 and 3 function area				Function/sub-function is to
	FA_1			provide interface
F_1		FA_{11}		provide physical interface
F_2		FA_{12}		provide electrical interface
F_3	FA_2			guarantee safety
F_4	FA_3			isolate interior
	FA_4			condense gas
		FA_{41}		convert energy
F_5			FA_{411}	start rotation
F_6			FA_{412}	maintain rotation
F_7		FA_{42}		convert movement
		FA_{43}		support mechanics
F_8			FA_{431}	mount mechanics in bearings
F_9			FA_{432}	lubricate mechanics
		FA_{44}		control gas flow
F_{10}			FA_{441}	control gas flow (entrance)
F_{11}			FA_{442}	control gas flow (discharge)
F_{12}			FA_{443}	isolate compression chamber
F_{13}		FA_{45}		execute compression

Once the functions and components have been analysed and delimited, the establishment of the relations between the two structures can begin. The result is displayed graphically in Figure 6.

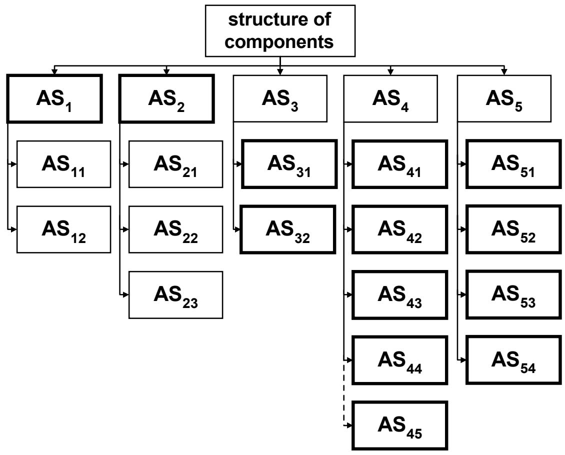


Figure 4 – Structure of the components of the EM Brazil

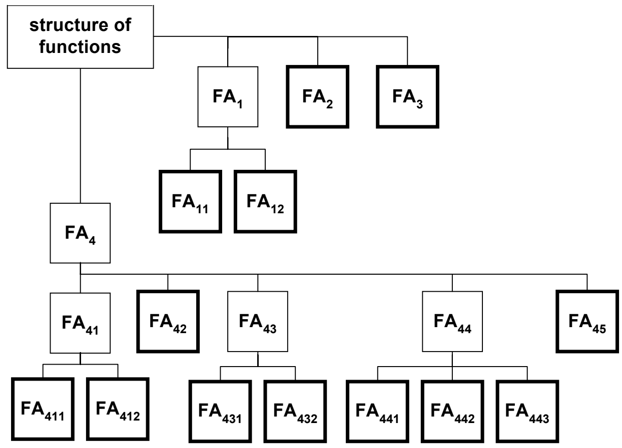


Figure 5 – Structure of functions for the EM Brazil

To take one example, it is interesting to note that $\{F_1\}$ and $\{C_1\}$ are related to each other. However, $\{F_1\}$ is also related to another four components. $\{C_1\}$ is related to another nine functions. The complexity of costing in these circumstances must be obvious.

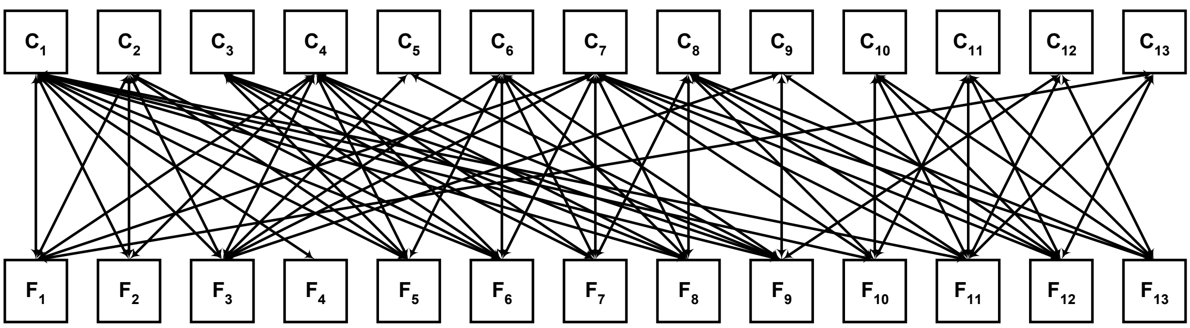


Figure 6 – Technological relations between the functions and components of the compressor

The first stage after the technological relationships between function and components are defined is the estimation of the $\{a_{jk}\}$ and $\{b_{jk}\}$ weightings to permit cost assignment across the functions and components thus related.

3. Subjective Estimation of the Weightings

3.1 Subjective distribution of probability

As the information available to the estimator who has the task of putting a figure on the weightings is so vague, it seems sensible to offer him or her the opportunity to give the estimate in the form of a confidence interval rather than a crisp number. Before this interval is expressed by the estimator, it is important to establish the distribution for the probability within the interval itself. The estimator can be given the choice of either the normal distribution curve or uniform distribution (see Figure 7), and may state which distribution he or she sees for the interval offered as estimate.

If the estimator decides to accept normal distribution, all values in the interval may, with same probability, be the unknown value. In the case of normal distribution, the central value of the interval has a higher probability of being the true value than do the lateral values. Outside the confidence interval the probability is equal to zero. In the software tool developed by the authors and applied at Embraco, normal distribution was approximated with a triangular distribution.

It would also be possible to apply other distributions of probability. To keep the system as simple as possible, only two choices were provided for application at Embraco.

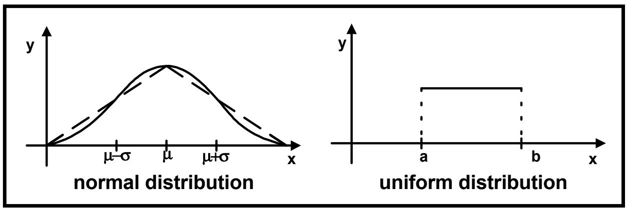


Figure 7 – Distributions of probability applied in Embraco

During use of the software tool to assist in "guesstimation" of a weighting, every estimator was asked to choose a distribution of probability according his subjective understanding. Figure 8 shows the estimates (interval and distribution) of four different estimators. In the figure, the area under the distribution curve for each estimate has been normalised to 100 units. In general use, different sizes of area of probability and thus different levels of influence of different estimators (who have different experience and, likewise, different levels of certainty) can be selected. The eight estimators came from various departments at Embraco and were classified into three groups. For each group, a different size of the area of probability was allocated according to the estimators' experience: 600 units for the certain group, 300 units for the mean group and 100 units for the group of uncertain estimators.

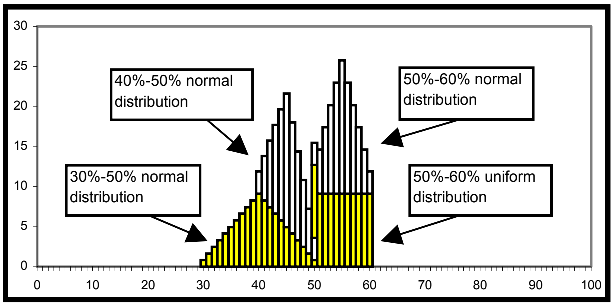


Figure 8 – Distribution of probability selected by four different estimators

The weightings have been computed in the tool as a weighted arithmetic mean of the histogram, derived from the areas of all the estimates in combination. This mean value can be interpreted as the most probable value from the viewpoint of all estimators.

For the calculation in the software tool, equation 13 was used; its variables are explained in Table 5.

Table 5 – Variables of equation 13

x	Weighted arithmetic mean
SP_{ej}	Sum of areas of probability
e	Number of the estimator {1…E}
j	Weighting a_{jk} or b_{jk}

$$\bar{x} = \left[\frac{1}{\sum_{j=1}^{101} \sum_{e=1}^{E} P_{nj}} \sum_{j=1}^{101} \left(j \cdot \sum_{e=1}^{E} P_{nj} \right) \right] - 1 \qquad (13)$$

3.2 Software solution to calculate the weightings

The software tool consists of the main menu and three Excel sheets. On the first sheet (see Figure 9) the functions and components are entered, and then their costs. In the second sheet (see Figure 10) estimates can be entered for every possible relation between the function and the components. This sheet includes:

- confidence intervals
- distributions of probability
- certainty of the estimators.

The software is designed to process the entries of a maximum number of ten estimators, who can give their estimates for both kinds of weightings, the $\{a_{jk}\}$ and the $\{b_{jk}\}$. The input of all data is assisted with dialog boxes.

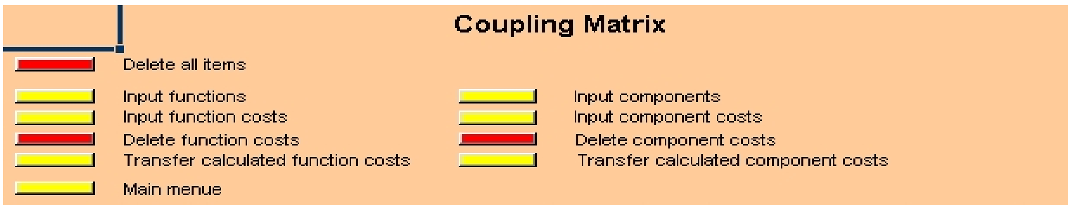
On the basis of the data inputted, both kinds of weightings are calculated with equation 13. Table 6 shows the $\{a_{jk}\}$ weightings calculated and Table 7 the $\{b_{jk}\}$ weightings. These weightings can now be applied for the calculation of function costs from the costs of components and vice versa. The result of the cost calculation of the compressor is finally shown in the third sheet (see Figure 11).

3.3 Results from the application

One way of obtaining a statement about the quality of the weightings produced with the assistance of the tool is to calculate the difference between the top-down and bottom-up calculations. This can be done by computing the component costs from the function costs using $\{b_{jk}\}$ weightings (top-down calculation). On the other hand, the function costs can be calculated from the component cost by using the $\{a_{jk}\}$ weightings (bottom-up calculation). In practice, there will be a difference between the original function costs and the top-down and bottom-up calculated ones. That difference can be understood as an indicator of the quality of the estimated weightings.

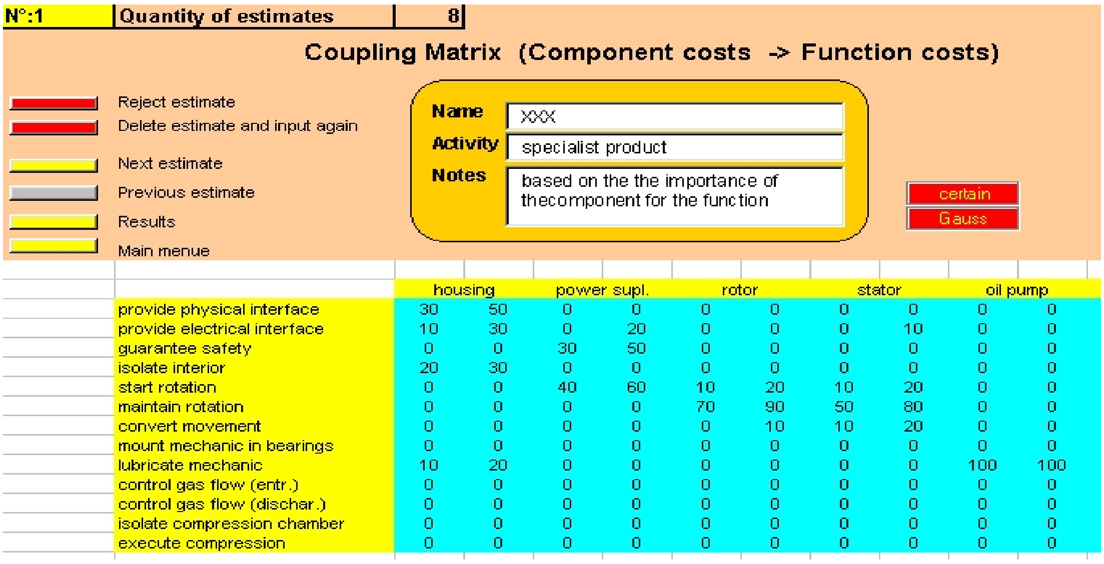
In the case of the compressor the difference was up to 179%, which gave rise to doubt whether the correct weightings could ever be calculated with this method. On the other hand, it is not clear how the difference was to be interpreted in this particular instance. The estimators were interviewed and it appeared that the poor quality of the estimates is mainly caused by a lack of understanding about the estimation task itself. In addition, the question regarding the importance of a component to a function and vice versa is a very complex one and should probably be subdivided into less complex sub-questions. If, for instance, a cheap component is very important to a function, the importance is probably not a good measure for the common fraction of costs.

As we can see in the example, the cost planning for functions and components (as used in Value Engineering and Target Costing) is not yet fully understood. Clearly, to improve the method of costs assignment requires further investigation and testing of hypotheses. The next chapter contains suggestions for this.



	Functions	Costs		Components	Costs
1	provide physical interface	2.437,98	1	housing	6.000,00
2	provide electrical interface	1.951,03	2	power suply	4.500,00
3	guarantee safety	2.266,80	3	rotor	2.000,00
4	isolate interior	1.930,52	4	stator	8.000,00
5	start rotation	4.318,18	5	oil pump	500,00
6	maintain rotation	5.866,45	6	crank shaft	2.000,00
7	convert movement	2.785,08	7	crank case	3.000,00
8	mount mechanic in bearings	2.770,14	8	piston complete	1.500,00
9	lubricate mechanic	2.704,39	9	oil	1.500,00
10	control gas flow (entr.)	1.750,35	10	gaskets and cove	1.000,00
11	control gas flow (dischar.)	1.331,66	11	valve parts	1.500,00
12	isolate compression chamber	1.633,00	12	suction chamber	1.000,00
13	execute compression	1.254,41	13	discharge tube	500,00

Figure 9 – Input of functions, components and their costs



	housing		power supl.		rotor		stator		oil pump	
provide physical interface	30	50	0	0	0	0	0	0	0	0
provide electrical interface	10	30	0	20	0	0	0	10	0	0
guarantee safety	0	0	30	50	0	0	0	0	0	0
isolate interior	20	30	0	0	0	0	0	0	0	0
start rotation	0	0	40	60	10	20	10	20	0	0
maintain rotation	0	0	0	0	70	90	50	80	0	0
convert movement	0	0	0	0	0	10	10	20	0	0
mount mechanic in bearings	0	0	0	0	0	0	0	0	0	0
lubricate mechanic	10	20	0	0	0	0	0	0	100	100
control gas flow (entr.)	0	0	0	0	0	0	0	0	0	0
control gas flow (dischar.)	0	0	0	0	0	0	0	0	0	0
isolate compression chamber	0	0	0	0	0	0	0	0	0	0
execute compression	0	0	0	0	0	0	0	0	0	0

Figure 10 – Input of the estimates

Table 6 – Calculated $\{a_{jk}\}$ weightings

	housing	power suply	rotor	stator	oil pump	crank shaft	crank case	piston complete	oil	gaskets and covers	valve parts	suction chamber	discharge tube
provide physical interface	36,91%	0,31%	0,00%	0,61%	0,00%	0,00%	3,06%	0,00%	0,00%	0,00%	0,00%	0,00%	13,73%
provide electrical interface	11,05%	21,19%	0,00%	4,18%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
guarantee safety	10,56%	32,10%	0,00%	0,61%	2,51%	1,00%	1,02%	0,00%	5,12%	0,00%	0,00%	0,00%	0,00%
isolate interior	32,18%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
start rotation	0,10%	41,26%	18,22%	24,65%	0,00%	5,98%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
maintain rotation	0,10%	5,14%	67,92%	51,13%	0,00%	7,17%	1,22%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
convert movement	0,00%	0,00%	12,01%	14,87%	0,00%	44,22%	1,22%	28,94%	0,00%	0,00%	0,00%	0,00%	0,00%
mount mechanic in bearings	4,40%	0,00%	0,53%	3,81%	0,00%	7,07%	67,71%	1,19%	0,00%	0,00%	0,00%	0,00%	0,00%
lubricate mechanic	4,11%	0,00%	1,33%	0,14%	97,49%	27,99%	0,00%	0,00%	90,89%	0,00%	0,00%	0,95%	0,00%
control gas flow (entr.)	0,30%	0,00%	0,00%	0,00%	0,00%	0,00%	2,45%	1,39%	0,00%	4,77%	40,22%	98,73%	0,00%
control gas flow (dischar.)	0,30%	0,00%	0,00%	0,00%	0,00%	0,00%	5,20%	0,90%	0,00%	11,13%	40,22%	0,00%	85,95%
isolate compression chamber	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	17,50%	5,81%	3,99%	71,45%	16,33%	0,00%	0,31%
execute compression	0,00%	0,00%	0,00%	0,00%	0,00%	6,57%	0,61%	61,77%	0,00%	12,65%	3,23%	0,32%	0,00%
	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 7 – Calculated $\{b_{jk}\}$ weightings

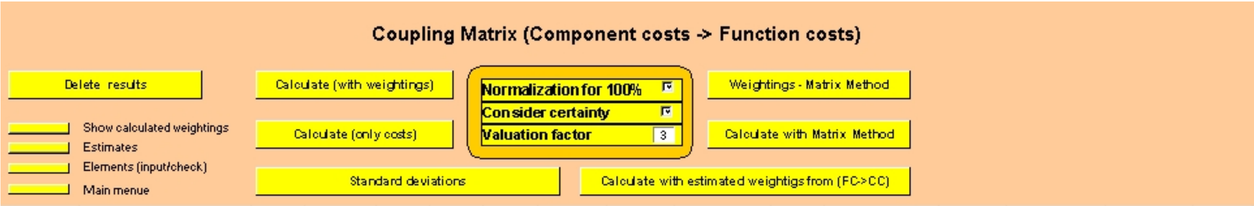
	housing	power suply	rotor	stator	oil pump	crank shaft	crank case	piston complete	oil	gaskets and covers	valve parts	suction chamber	discharge tube	
provide physical interface	94,01%	0,62%	0,00%	1,25%	0,00%	0,00%	1,66%	0,00%	0,00%	0,00%	0,00%	0,00%	2,46%	100%
provide electrical interface	22,32%	65,89%	0,00%	11,79%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
guarantee safety	35,08%	52,81%	0,00%	2,70%	1,54%	1,93%	1,93%	0,00%	4,02%	0,00%	0,00%	0,00%	0,00%	100%
isolate interior	100,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
start rotation	0,09%	45,28%	20,22%	27,35%	0,00%	7,07%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
maintain rotation	0,09%	11,99%	35,01%	39,68%	0,00%	11,67%	1,56%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
convert movement	0,00%	0,00%	6,86%	6,86%	0,00%	53,59%	5,32%	27,37%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
mount mechanic in bearings	10,53%	0,00%	0,20%	3,60%	0,00%	11,48%	69,29%	4,89%	0,00%	0,00%	0,00%	0,00%	0,00%	100%
lubricate mechanic	3,77%	0,00%	2,78%	0,20%	19,85%	19,39%	0,00%	0,00%	52,81%	0,00%	0,00%	1,19%	0,00%	100%
control gas flow (entr.)	0,66%	0,00%	0,00%	0,00%	0,00%	0,00%	1,75%	5,76%	0,00%	4,37%	62,83%	24,64%	0,00%	100%
control gas flow (dischar.)	0,59%	0,00%	0,00%	0,00%	0,00%	0,00%	3,75%	6,12%	0,00%	10,66%	60,30%	0,00%	18,56%	100%
isolate compression chamber	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	16,56%	7,55%	3,61%	47,42%	24,78%	0,00%	0,09%	100%
execute compression	0,00%	0,00%	0,00%	0,00%	0,00%	14,91%	1,24%	75,38%	0,00%	4,14%	4,14%	0,18%	0,00%	100%

1.2 The characteristics of a subjective estimation

As "guesstimation" of weightings involves estimation using subjective judgements, this concept is here first examined and defined.

It should be noted that a distinction can be made in the first instance between statements about present time and those about future time. To take the present tense: a statement here may be based on observation, determination and measurement (or a logical conclusion therefrom), and if so, can be seen as an "objective" estimate. It may, on the other hand, be a statement based on a subjective view, in which case, if it is for estimation purposes, it will not have the incontrovertible characteristics of the first type mentioned, and could be called a "guesstimation".

In the same way, where a statement in the field under discussion refers to future time, it can, on the one hand, be founded on statistical data from which a function or trend has been derived. On the other hand, it may be a statement about the future based on information adopted selectively as the result of the psychological principle of selective attention. This is, of course, subjectively variable from person to person. Here, also, the prediction is a "guesstimation".



	housing	power suply	rotor	stator	oil pump	crank shaft	crank case	piston complete	oil	gaskets and covers	valve parts	suction chamber	discharge tube	
provide physical interface	2.214,77	13,89	0,00	48,89	0,00	0,00	91,78	0,00	0,00	0,00	0,00	0,00	68,66	2.437,98
provide electrical interface	663,25	953,70	0,00	334,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1.951,03
guarantee safety	633,64	1.444,44	0,00	48,89	12,55	19,92	30,59	0,00	76,77	0,00	0,00	0,00	0,00	2.266,80
isolate interior	1.930,52	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1.930,52
start rotation	5,92	1.856,48	364,36	1.971,89	0,00	119,52	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4.318,18
maintain rotation	5,92	231,48	1.358,47	4.090,45	0,00	143,43	36,71	0,00	0,00	0,00	0,00	0,00	0,00	5.866,45
convert movement	0,00	0,00	240,10	1.189,65	0,00	884,46	36,71	434,16	0,00	0,00	0,00	0,00	0,00	2.785,08
mount mechanic in bearings	264,11	0,00	10,53	304,75	0,00	141,43	2.031,41	17,90	0,00	0,00	0,00	0,00	0,00	2.770,14
lubricate mechanic	246,35	0,00	26,54	11,41	487,45	559,76	0,00	0,00	1.363,36	0,00	0,00	9,53	0,00	2.704,39
control gas flow (entr.)	17,77	0,00	0,00	0,00	0,00	0,00	73,42	20,89	0,00	47,66	603,33	987,29	0,00	1.750,35
control gas flow (dischar.)	17,77	0,00	0,00	0,00	0,00	0,00	156,03	13,43	0,00	111,35	603,33	0,00	429,77	1.331,66
isolate compression chamber	0,00	0,00	0,00	0,00	0,00	0,00	524,98	87,13	59,88	714,47	244,97	0,00	1,57	1.633,00
execute compression	0,00	0,00	0,00	0,00	0,00	131,47	18,36	926,50	0,00	126,53	48,38	3,18	0,00	1.254,41
	6.000,00	4.500,00	2.000,00	8.000,00	500,00	2.000,00	3.000,00	1.500,00	1.500,00	1.000,00	1.500,00	1.000,00	500,00	33.000,00

Figure 11 – Results of the cost calculation – function costs and component costs

In the light of this, one sees that the weightings $\{a_{jk}\}$ and $\{b_{jk}\}$, not being susceptible to analytical methods, require subjective estimation in respect of both current and future time. However, against subjective estimations there have been several reservations expressed [see Lechner 1994, p. 101f]:

♦ Makeshift solution, only for use when the preconditions for analytical methods are not fulfilled

♦ Not susceptible of analysis (inscrutable), because...

♦ impossible to trace connections between the actual object being estimated and the subjective estimate.

These connections are, in effect, a "bridge" made subjectively by the estimator. The subjective influence of the estimator can never be fully excluded and, hence, a certain level of inscrutability is unavoidable.

Without denying the truth of this standpoint, one can, however (with Lechner, op. cit.), give some positive views of subjective estimation:

♦ There is no rational alternative

♦ 70% of all predictions in the field of business administration are based on subjective estimates

♦ Less effort is required in preparation of data

♦ The method does at least address the changing knowledge base, offering the chance of dynamic processing.

3.5 Psychological aspects of a subjective estimation

Even subjective estimation requires the provision of objective information. This information is available in the enterprise and it is possible for others to access or edit it. The subjective knowledge of the estimator, however, is stored in an inaccessible form and cannot be edited [see Lechner 1994, p. 18f].

Steinberg investigated how information is processed in people's minds from an abstract viewpoint and came to the conclusion that the process can be seen as having four phases (see Anderson 1996, pp. 11-13):

♦ Perceiving the stimuli,

♦ Drawing comparisons,

♦ Reaching a decision and

♦ Generating an answer.

As a first step, a person perceives and decodes the stimuli. Then comparisons are drawn with known situations and, as a result, the person comes to a decision as to which known situation is equal or similar to the stimuli. Finally the answer must be expressed. (see the upper half of Figure 12).

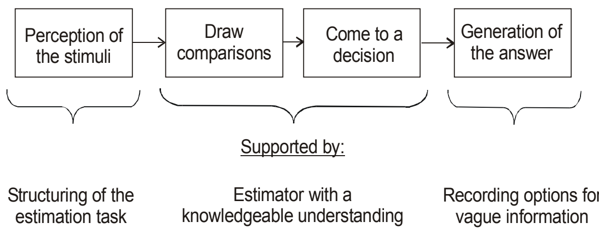


Figure 12 – Structure of the "guesstimation" process according to Steinberg's abstract theory of information processing

By analysing the procedure in information processing, this paper attempts to reduce the part played proportionately by the estimator's subjectivity, and to increase the objectivity and transparency of the estimate. There are three locations (see the lower half of the Figure 12) where the estimation procedure might be improved:

♦ Structuring the estimation task (would affect perception),

♦ Selection of the estimator (would modify cognition),

♦ Output of the estimate (could change the nature of representation).

Improvement at these locations could raise the quality of estimates. Statisticians normally describe the quality of estimates as distributed according to the following three most important statistical parameters [see Bohley 2000, p. 530-533]:

♦ Unbiasedness,

♦ Consistency and

♦ Minimum variance.

The estimator, now seen as a mathematical term, $\{\hat{\Theta}\}$, is unbiased, when its distribution has the expected value $\{\theta\}$ without bias (see equation 9). The estimator should be consistent. The output of a consistent estimator $\{\hat{\Theta}\}$ should distribute closer to the expected value $\{\theta\}$ as sampling size {n} increases. The estimator $\{\hat{\Theta}\}$ is consistent, if for every $e > 0$ the limiting value of probability shown in equation (10) is true.

$$E(\hat{\Theta}) = \theta, \quad \lim_{n\to\infty} P\,(|\hat{\Theta} - \theta| < e) = 1 \qquad (9,10)$$

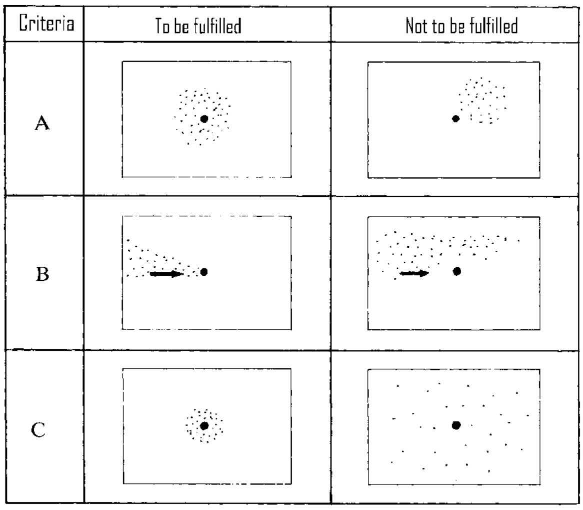


Figure 13 – Criteria for the evaluation of estimates (A = unbiasedness, B = consistency, C = minimum variance) [see Bohley 2000, p. 530]

For every sampling size {n}, the estimator should also have minimum variance. The estimates should disperse around the expected value as closely as possible. The estimator is called efficient (with minimum variance), if it is unbiased and the equation (11) is valid. $\tilde{\Theta}$ in (11) stands for any other unbiased estimator. Figure 13 shows pictorially the three statistical criteria. For a good estimate all the criteria on the left would be fulfilled.

$$V(\hat{\Theta}) V(\tilde{\Theta}) \qquad (11)$$

3.6 Producing the weightings

The procedure to produce each weighting, or, in the terms of the psychological aspects analysed in the previous chapter, to achieve the expression of an estimate, can be structured in the following three steps:

♦ Structuring of the estimation task, to support perception

♦ Cognitive processing, which is, in effect, evaluation of the criteria

♦ Aggregation of the evaluations from the previous step.

Step one, structuring the estimation task, will include the identification of the criteria for the evaluation of the weightings and the formation of a clear tree structure. Multicriteria Decision Making [see Brugha 1997; Strebel 1972] offers a range of helpful instruments, which is discussed in Schlink/-Schneider/Höhne 2001b. In principle, the criteria, which could be either economic or technical, should be selected on relative importance and on whatever is the main aim for the weightings. In general, because the weightings will be used for the assignment of costs, the criteria for their estimation should be economic rather than technical. It might well be of assistance to use technical or physical criteria if there is any clear logical relationship in the m:n relation between functions and components based on technical parameters, but this is not usually the case.

As criteria for the appropriate assignment of costs, one should take the elements of which the costs to be assigned consist (the cost items). To specify further detail, it will be necessary to clarify such aspects as the volume of costs to be assigned, especially the volume of overhead costs which can be influenced and hence are relevant.

In step two, the individual criteria are evaluated by the estimator. As mentioned above, the evaluation takes place through perception, cognition and expression. Cognition may give the estimator a vague idea of the evaluation for a criterion, for the expression of which it should be possible to provide the estimator with suitable tools. One common form of expression would be as a deterministic variable; a stochastic or linguistic variable is another alternative.

The aggregation of the evaluations depends on both the structure of the estimation task and the form in which the evaluation of a criterion has been expressed (e.g. as crisp number, confidence intervals or fuzzy numbers). Thus the aggregation of the criteria will have to be adapted to the expression method applied.

4. Hypotheses

Three hypotheses have been formulated to address the observations under "Subjective Estimation of the Weightings" in section 3. Each of them is related to one psychological aspect of information processing and pursues the aim of improving the quality of estimates so made.

♦ Hypothesis 1 (perception):

The more detail there is in the way the estimation task is structured, the less is the subjective influence of the estimator, and, as a result, the better is the quality of the estimate.

♦ Hypothesis 2 (cognition):

The higher the estimator's degree of knowledgeable understanding about the subject of the estimation task, the less is his uncertainty, and, as a result, the better is the quality of the estimate.

♦ Hypothesis 3 (representation):

The better the recording options for vague information, the better the estimator can articulate imprecise evaluations of criteria, and, as a result, the better is the quality of the estimate.

5. Conclusion

The assignment of product costs to the functions and components is clearly an important aspect of cost-oriented product design. The paper applies the method with a compressor in Brazilian industry and mentions the bad quality of the costs assignment made between functions and components. It emphasises the existence of an unavoidable subjective influence when weightings for such cost assignment are estimated. Various aspects with the potential of reducing the subjectivity and hence of improving the quality of such estimations are presented.

The hypotheses formulated have yet to be empirically verified.

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