COST CALCULATIONS SUPPORTING CONSTRUCTION AND DESIGN

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Summary

Engineers dealing with construction and design have the task to create products with given technical, technological and even with appropriate economical parameters. It is well known that the major part of manufacturing costs can be influenced by construction. The engineers mentioned above are generally inexperienced in cost analysis. They should thus be given methods, the practical application of which does not require special skills; they should be easy to use and rapid to learn. These conditions can generally be met by computer application. With the help of microcomputers one can analyse costs in detail, at a fairly early stage. Cost analyzing systems should fulfil two major requirements. First they should provide the possibility of forecasting the costs of a product at expected marketing trends. On the other hand they should support construction and design activities on the component level, thus allowing cost-appropriate design and the choice between technical alternatives.

Due to permanent changes in world economy and to rapid technical development companies are forced to regularly revaluate their product pattern, and to appear with new products from day to day. These changes make adaptibility and market flexibility essential, both on the micro- and macro-economic level. This urgent constraint is interpreted by I. T. Berend [1] in the following way: "Things that have been succesful on the international market for some years might become out-of-date within five or ten years. This situation cannot be avoided—we have to adapt ourselves to it."

But where is the key to successful adaptation? It is difficult to answer this question, since even the most unexperienced will see that the problem has many components and aspects.

All companies dispose of limited resources only for solving production tasks and restricted resources force them to use them efficiently. Profitability of production is defined fundamentally by the amount and structure of resources used for production. The result depends however on the products themselves too: on the type of product, for which they are consumed. Product pattern is one of the company's key issues.

Significant research has been done in the recent years in analyzing questions of production and product pattern. A part of it summarizes all the technical and economic factors into a criteria system which supports medium- and long-term planning [2]. Another field of research is of a methodological character; the methodological questions of optimum calculations are studied to promote short term plans [3, 4]. The results of the latter research call attention to the fact that algorithms, properly selected, might only be used successfully with exact, practical data.

When changing product pattern, one of the most common tasks is to introduce a new product. To do this, one has to introduce new constructions or the current products are to be updated.

Raising profitability is always one of the main criteria here. Profitability depends mainly on the product's technical/economical parameters. Technical parameters are defined by the demand side, which should be perfectly fulfilled. Economical parameters, first of all production costs, also, need the same attention.

The success in reducing production cost depends on production itself, but also on construction. One cannot decrease cost, if the designer has only technical but no economical parameters to fulfil. In the machine industry—according to *Menges* [5] 75% of the total product cost is determined by the construction, and only 6% depends on production.

Based on this, cost-planning and cost-analyzing methods are needed, with the help of which production costs can be estimated as early as at the construction phase. Costs are mainly material costs and operational costs. Cost analysis in the construction phase may be carried out by co-operation between the designer and the technologist. Alternative versions of the whole construction and of its parts are to be analyzed and evaluated on the basis of previous cost estimates.

What is the basis of accepting a cost estimate?

Speaking of production costs, the idea of total prime cost always emerges. Total prime cost is the share of the company's total cost per product unit. This definition raises problems even if the company has one single product. In the machine industry, firms always have a wide scale of products, consequently the above mentioned problem is more complex. What is this problem caused by? How can we solve it?

It is impossible to give an exact definition of the total prime cost. This statement has well-proven theoretical grounds. One of the grounds is that the costs are not directly proportional to the volume of production. There are so-called fixed costs, which do not give a constant value on unit level (divided by the volume), since these costs depend on the volume. The other part of the costs is directly proportional to the quantity of production, they can consequently be expressed in terms of cost per unit, as well.

In consequence of the above statements, there is a portion of costs which can be traced exactly in every product. This part is therefore suitable for cost calculations. The correctness of this need not be proved, since according to the known methodology of direct costing, fixed costs can be separated when analyzing costs on product level [4, 7].

The so-called coverage-bonity factor, well known from direct costing literature is a characteristic indicator of probability. It is equal to the quotient of coverage (per unit coverage) and the income (price) [6, 8]. If a product's coverage-bonity factor exceeds the average coverage-bonity of the firm, the product is regarded as more profitable than the average. To reach this situation could be one of the aims of engineering.

In the phase of construction and design only direct costs can be calculated. It is therefore favourable to take costs as a basis of evaluation in this phase, and not another, synthetized indicator. Since the price of a product depends mainly on market conditions and less on costs, even the price is known to the designer. Supporting a constant price, a limit can be defined for the proportional costs, which, if overstepped, would reduce the average profitability.

The above statement can be formularized as follows: The aim is to have products designed with:

$$\frac{C}{I} \leq \frac{c_u}{p_u} \tag{1}$$

C = coverage of the firm
I = income of the firm
c_u = coverage per unit of the new product
p_u = price per unit of the new product

Taking the average company-coverage as a threshold value of the product's coverage-bonity, the required coverage per unit can be defined with a given price. Since coverage per unit is equal to the difference of unit price and proportional costs (2), the threshold value of costs can also be defined, over which the expected profitability is damaged (3).

$$c = p - e_p \tag{2}$$

where
e_p = proportional costs (expenditure) per unit

$$e_{p\max} = p_u\left(1 - \frac{C}{I}\right) \tag{3}$$

where
$e_{p\max}$ = threshold value of costs.

The threshold cost is of a proportional nature and its value is close enough to the so-called direct costs. It is well known that direct costs can always be defined. In the phase of construction and design direct costs are easily traced and controlled through the co-operation of designer and technologist.

When defining the threshold value of direct production costs, a known sale price has been assumed. Sale price may however be changing; it is therefore useful to analyze the product's direct cost as a function of the sale price (Fig. 1).

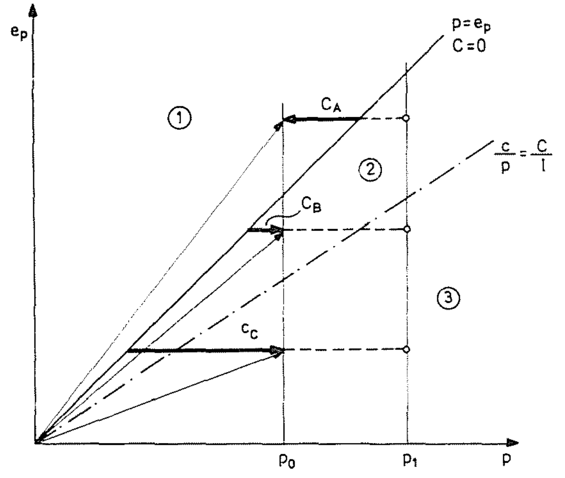


Fig. 1

It can be seen from the figure that there are three different zones of profitability. The boundary lines between the zones play a major role. The boundaries of area 1 are the line $c=0$ and axis e_p. This area is forbidden, since products falling here have a negative coverage per unit, causing thus losses to the company. Area 2, between lines $c=0$ and $\frac{c}{a}=\frac{C}{I}$ has already a positive coverage but with a bonity factor lower than the company average. Area 3 is the favourable one. The amount of coverage produced here raises the average profitability of the firm.

The figure shows three cost-versions of a product based on an assumed, p_0 price. Of these A, B, C versions only C meets our requirements. When modifing unit price ($p_0 \rightarrow p_1$) the coverage per unit changes favourably. Assuming price p_1, even version B is favourable. When extra costs in case B might be justified by extra functions or better quality, a higher price may probably be reached. There is however no hope to raise coverage through price, when higher costs are due to a less favourable construction.

It is worth while to examine the relation of costs and design possibilities. Fig. 2 shows the proportional costs and price for a given product A. Originally the product had c_0 coverage per unit and $\frac{c_0}{p_0}$ bonity. When designing a better (modified new product, the aim is twofold: maintaining coverage per unit and raising bonity. The diagonally shaded area on the figure is unfavourable since both c and $\frac{c}{p}$ values are decreasing. In the squared area $\frac{c}{p}$ is increasing, but with

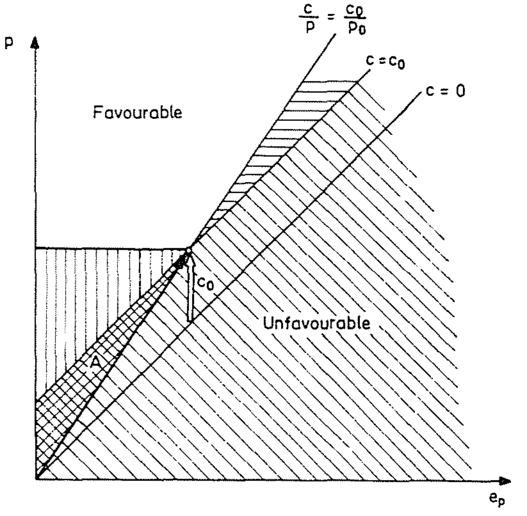


Fig. 2

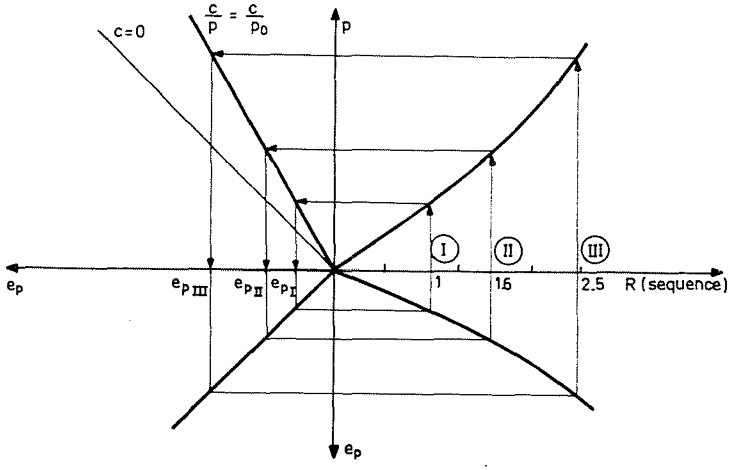


Fig. 3

less coverage; it is therefore unfavourable too. The vertically shaded part is advantageous—it assumes however discount price. In the horizontally shaded area there is extra coverage, but it does not raise the average rentability. Most favourable is the empty area, where both indicators are changing in favourable direction.

In case of product families and construction sets it is advantageous to have good and equal coverage bonities for all the members of these. Assuming a given sale price, the required cost values may be defined by using the nomogram in Fig. 3.

Defining the threshold value of direct costs means the specification of a very important criterion. It is therefore the aim during construction and design to define direct costs adequately.

How to define direct costs?

There are four important cost factors to be taken into consideration when defining direct costs:

— direct material costs
— direct wages and charges
— extra costs of production
— other direct cost elements.

Various data should be used when calculating each of the above elements. A certain part of these date depends on the construction, others are constant. From the latter a simple data base can be built up. Through its continuous updating cost calculations can always be made quickly and adequately. Using a personal computer makes this work even more simple and fast. When different versions are to be compared, or the influences of possible modifications should be estimated, computers are especially useful.

Mechanical systems, machines, equipment, etc. consist of components, subsystems. Like the technical construction, costs are also made up of elements. When looking for the costs of product level, one should therefore begin with components; the total construction's cost is to be built up from these.

Defining direct cost elements is based on construction and technological data. Regarding the single elements, the following remarks should be made:

Direct material costs

When analyzing material costs, difference should be made between components produced by the company, and those produced from outside. In the latter case the situation is simple: the type, quality and quantity is fixed in the construction, the costs are thus given. Items of this type (e.g. electrical components, hydraulical and pneumatic building blocks, bearings etc.) are always material costs.

In the case of home-produced components the task is more complex: the sizes shown in the construction chart do not define the material requirement alone. Material requirement depends strongly on technology. Material requirement calculations can only be made, when production methods are more or less adequately known. Therefore a larger amount of information is needed; beyond qualities and quantities other data should also be taken into consideration. These are generally the following:

— material quality
— sizes of the finished product
— sizes of the raw material
— unit price
— material requirement per unit component
— specific weight.

Material quality and finished product size are a question of construction. Raw material size and material requirement are at the same time a function of production type. Fig. 4 illustrates material requirement differences, resulting from different manufacturing methods (direct cutting, welding and forging).

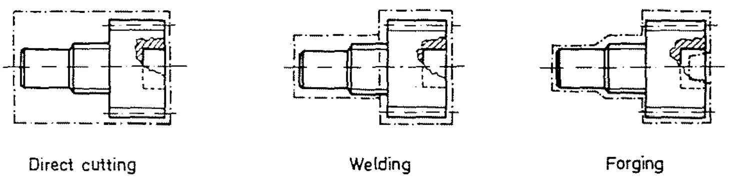


Fig. 4

Material requirement depends also on the relation between finished product sizes and common raw material sizes. Inevitable losses can considerably raise the material requirement, which is especially infavourable in case of expensive materials.

There are material requirements which can not be seen in construction charts; these turn out through analyzing assembly and surfacing instructions. These are mainly materials of welding, soldering, surfacing or paints, adhesives. Material costs of this type can primarily be defined with the help of technological parameters. (Standards of material consumption are contained in technological instructions.)

Energy costs are also a part of material costs. These can only be taken into consideration, when the technological energy demand is computable based on technical parameters.

Direct labour and accessory costs

Labour costs depend on manufacturing time and labour per unit of time. Manufacturing time can be calculated from technological parameters—should they be absent, they are to be estimated. Various manufacturing operations require different skills. These are to be treated separately, since the difference between the related wages quite considerable is.

Taxes are functions of labour through given formulas, which are constant over longer periods (e.g. for a year).

Extra costs of manufacturing

Costs of tools and appliances fall into this category. The question when it is expedient to make special devices and tools and when it is more economical to use universal tools will not be analyzed here, only the methods how the designer should take into account the tooling costs actually considered. The methods how defining extra costs derived from planned appliances are treated instead.

Assuming that the instruments analyzed belong to a single component type, their costs also belong to this component. Costs are strongly dependent on the instrument's durability. Instrumentation costs per component are thus equal to a quotient of tool price and the quantity of products made during its lifetime. It is often the trouble that physical durability exceeds the planned production volume by far.

Other (miscellaneous) direct costs

Generally these cannot be defined at an early stage of construction and design. Since their order of magnitude is insignificant compared to the previous cost elements, they can be neglected.

Relation between costs, functions and structural elements

The designer's task consists in constructing structural elements being able to perform given functions. Functions can however be performed by different solutions. Costs related to a specific function are dependent on the technical solution chosen. It is well known from the logic of value analysis that value is defined by the cost-function relationship [9]. It is therefore desirable to arrange the costs into groups of individual components and subunits, in a manner that they should not only yield information on the costs of the final product, but that the costs of individual components and subunits should also be made clear.

The main function and the subfunctions can be determined separately. Setting up the function tree showing the hierarchical order of functions is useful also from the point of view of cost analysis. There is a close relationship between this hierarchical function structure and the elements of the product's

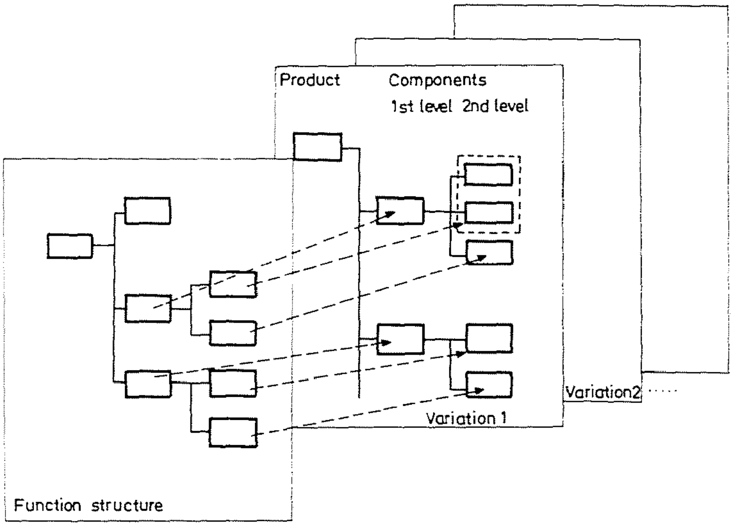
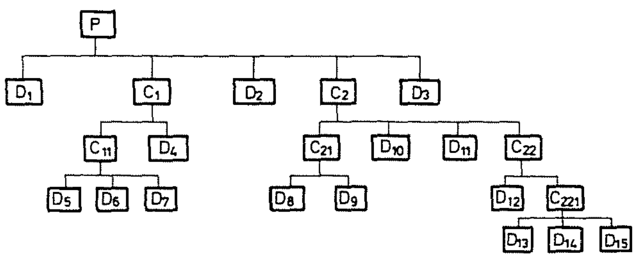


Fig. 5



Nº	Component	Name	Material	Size	costs				
					e_m	e_v	e_{ma}	e_t	Σ
1									
2									
3									
⋮									

Fig. 6

family tree [10]. Through an exploration of this relationship the costs of structural elements and subfunctions may be defined. The example shown in the diagram assumes different functional realizations.

Cost calculations should always be based on the real structure; the product's family tree can thus be the starting point. Having defined the cost of the elements, the functions' costs can also be calculated, based on the relations shown in Fig. 5.

Composing a list of materials constitutes an organic part of construction and design. This can be done with the help of the family tree [11]. In the case of the family tree shown in Fig. 6 it is desirable to set up 7 lists of materials to be handled separately. All of them contain the data of one assembly unit.

The table, supplementing the above diagram contains the well-known list of material and columns, to be used for cost calculations.

Finally let us consider the computer flow-chart of cost analysis (Fig. 7.).

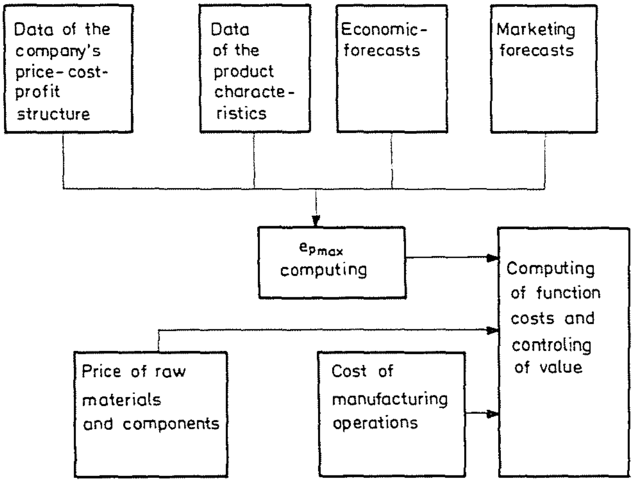


Fig. 7

To define the construction costs a data base is needed, consisting of two main parts. To define the marginal direct costs, economical parameters are necessary, characteristic of the product and of the whole company's management. These parameters serve as a basis of the coverage-oriented cost calculations (direct costing).

Some of these:

— data of the company's price-cost-profit structure
— product characteristics
— economical (price) forecasts
— marketing forecasts.

The other part of the data base supports the definition of prime production costs. It contains:

— price of raw materials and components

— costs of manufacturing operations.

The first part of the data base supports the creation of standards; the second part is for cost calculations.

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