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STREAMLINED COSTING AND TARGETING OF PRODUCT FUNCTIONS IN VALUE ANALYSIS

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1. Introduction

From first practices introduced at General Electric half a century ago [Miles 1972], Value Analysis (VA) has evolved into a structured methodology [EN 12973] which helped to improve market success of countless products of very different type and complexity.

Redesign actions are more effective when those functions that generate costs and performances are most important for customers. Therefore, key to value increase is a careful recognition of product functions, which are assessed through cost, performance and importance measures. Following this concept, modern VA [Fowler 1990] involves the following teamwork-based activities (Fig. 1a):

- collection of detailed cost and performance data on current product;
- identification of product functions;
- evaluation of performance, importance and cost for each function;
- selection of critical functions deserving the strongest redesign efforts;
- creative generation of innovative concepts for the fulfilment of selected functions;
- development of solutions from the most promising concepts.

In principle, VA should allow better profit advantages than other redesign methodologies focused on cost reduction do. Yet, time and resource intensity has discouraged its use in SMEs, where redesign projects of several months can be impractical. The present work identifies the reason of these difficulties in the critical phase of function analysis [Snodgrass 1986], where the VA team undertakes the complex effort of describing and evaluating the product at the function level. Procedures have been proposed to streamline function analysis so that reliable results could be achieved in this phase with reduced amounts of time and resources.

As described in section 2, the contribution focuses on the costing and targeting subphases of function analysis. Sections 3 and 4 describe the modified procedures proposed for the execution of these two critical tasks. Section 5 illustrates a test example and section 6 summarizes advantages and application perspectives of presented results.

2. Critical issues in function analysis

Input information to function analysis, collected in the preparation phase, includes details on product operation, cost and user experiences. In order to find a set of functions to be considered for further redesign efforts, the analysis steps through the following three subphases (Fig. 1b):

Function definition – Product functions are identified from a detailed study of product operation. A hierarchy of dependence relations among functions is recognized and graphically represented by a FAST diagram (Function Analysis System Technique, [ASTM E 2013]).

Function costing – Part and assembly costs are allocated to functions at the lowest level of the hierarchy. When a part covers more than one function, a fraction of part cost is calculated for each of them.

As a result, a cost is associated to each function.

Function targeting – From market surveys, two additional measures are estimated for each function. They express to what degree the function is satisfied in current product and its importance in purchasing decisions. This step excludes basic functions and involves only supporting functions, which determine perceived product quality. Redesign priorities are recognized on functions showing improper combinations among values of cost, satisfaction and importance measures (value mismatch).

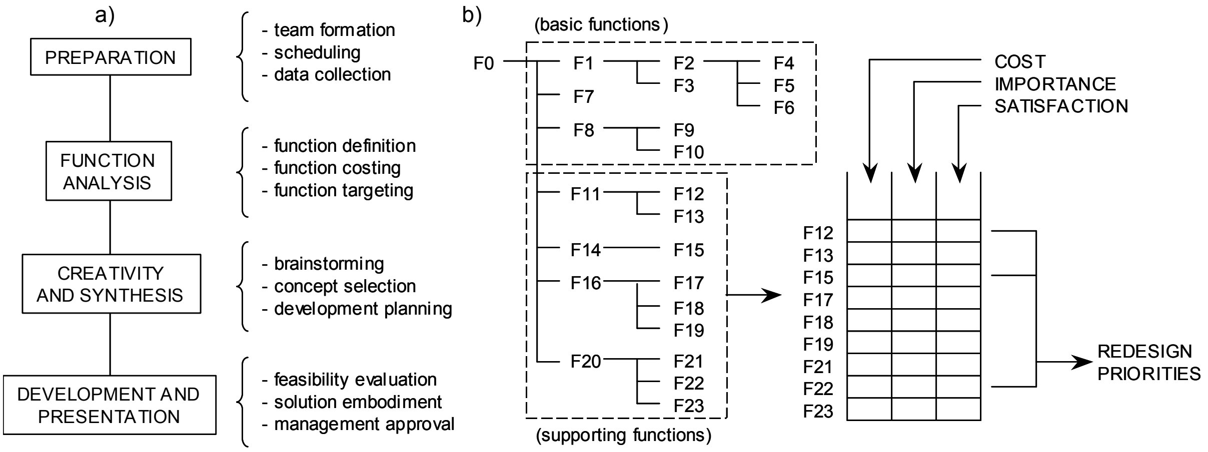


Figure 1. VA methodology and function analysis

The above procedure reveals its main shortcomings in the two following aspects:

- Calculation of function costs requires a careful analysis of all product components, with the purpose of evaluating design reasons behind their properties. For complex products, this can be a tedious task, whereas in many cases most parts give a marginal contribution to total cost.
- No formal procedure seems to be available to select target functions. The usual suggestion is to consider those functions which are either undersatisfied or too costly for their importance. Such criteria give no hints on the specific kind of action needed to improve product value.

Modified costing and targeting procedures to overcome these problems are described in the following.

3. Simplified costing procedure

Function costing consists in re-allocating part and assembly costs to functions. For a product with n parts and m functions, the following calculation provides the cost C_i of the i-th function:

$$C_i = \sum_{j=1}^{n} a_{ij} c_j \quad , \quad i = 1, \dots m \tag{1}$$

where c_j is the cost of the j-th part, including a fraction of total assembly cost (with $c_j \geq c_{j+1}$), and a_{ij} is the share of c_j attributed to the i-th function ($0 \leq a_{ij} \leq 1$).

The a_{ij} are not easy to evaluate, since a part usually covers more than one function. Part-function relations, i.e. the (i, j) pairs for which is $a_{ij} > 0$, are known from the function definition subphase. Accurate methods, such as particle analysis and equivalent allocation [Fowler 1990], are used to split part costs into function shares. They involve a careful examination of manufacturing operations responsible for those properties (material, geometry, accuracy, surface finish) which are related to different functions. Therefore, function costing is very expensive in terms of time and resources.

In the proposed procedure, a_{ij} are accurately evaluated for the only k parts with the highest costs ($k \leq n$), while the costs of remaining parts are divided into equal shares. In the calculation of costs $C_{i(k)}$ from (1), this simplification involves an error e_k which, consistently with the targeting procedure described in the next section, is evaluated from normalized function costs:

$$e_k = \max \left| \left[C_{i(k)} / \max\left(C_{i(k)}\right) \right] - \left[C_i / \max\left(C_i\right) \right] \right| \tag{2}$$

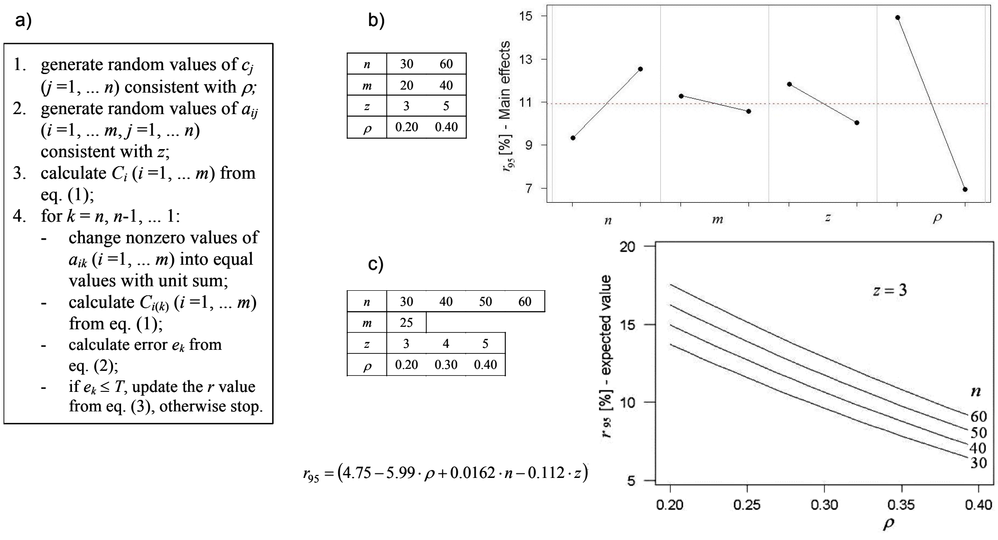
Since estimates of function costs will help to orient decisions in the targeting subphase, error e_k must be lower than a tolerance T, here assumed equal to 5%. Such condition defines the residual cost

$$r = \left(\sum_{j=k+1}^{n} c_j \bigg/ \sum_{j=1}^{n} c_j \right)_{e_k \leq T} \tag{3}$$

which can be safely neglected in function costing. This parameter should be calculated for a product subject to a VA study in order to plan a costing procedure with a proper degree of simplification.

3.1 Evaluation of residual cost

A rough estimation of r could rely on such basic data as n and m. However, the tendency of parts to cover many functions and the presence of overexpensive parts are certainly related to the influence that single a_{ij} values have on function costs. Therefore, two additional factors are used for residual cost calculation: the average number z of functions per part and the fraction ρ of parts accounting for a given fraction (assumed equal to 80%) of product cost. The data set (n, m, z, ρ) is known before function costing and is used to evaluate r through a simulation whose steps are listed in Fig. 2a.
Repeated simulation runs result in a frequency distribution for r, from which a reference value is picked so as to guarantee a given probability (e.g. 95%) to limit error e_k within tolerance T.


a)

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1. generate random values of $c_j$ ($j$ =1, ... $n$) consistent with $\rho$;
2. generate random values of $a_{ij}$ ($i$ =1, ... $m$, $j$ =1, ... $n$) consistent with $z$;
3. calculate $C_i$ ($i$ =1, ... $m$) from eq. (1);
4. for $k = n, n$-1, ... 1:
    - change nonzero values of $a_{ik}$ ($i$ =1, ... $m$) into equal values with unit sum;
    - calculate $C_{i(k)}$ ($i$ =1, ... $m$) from eq. (1);
    - calculate error $e_k$ from eq. (2);
    - if $e_k \leq T$, update the $r$ value from eq. (3), otherwise stop.
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b)

n	30	60
m	20	40
z	3	5
ρ	0.20	0.40

c)

n	30	40	50	60
m	25			
z	3	4	5	
ρ	0.20	0.30	0.40	

$$r_{95} = (4.75 - 5.99 \cdot \rho + 0.0162 \cdot n - 0.112 \cdot z)$$

Figure 2. Costing procedure: a) simulation model, b) effects on residual cost, c) regression

3.2 Effects of input factors on residual cost

To study the conditions allowing a higher degree of simplification of the costing procedure, the above simulation has been applied to different combinations of factors (n, m, z, ρ). Variation of residual cost has been observed through the value of r_{95}, the fifth percentile on 100 random instances of products consistent with input factors.
It has been observed that r_{95} is normally distributed over repeated simulation runs. This has suggested to adopt it as the response of a 2^4 factorial plan with 10 replications for each factor combination. Results of the simulation plan are shown in Fig. 2b. As confirmed by an analysis of variance, r_{95} is significantly influenced by the main effects of three factors (ρ, n and z in decreasing order of importance) without relevant interactions among them. The highest degrees of simplification are acceptable for products with many parts, uneven cost distribution (low ρ) and few functions per part.

A second simulation plan has been conducted to estimate a predictive model r_{95} (ρ, n, z). Due to a homogeneous variance over all variable combinations, the square root of r_{95} has been adopted as the response of a linear regression model with 85% correlation, normal residuals and no lack of fit. Fig. 2c shows the expected values of r_{95} estimated from the model for a given value of z.

4. Targeting rules

Targeting selects critical functions for subsequent redesign efforts. This can viewed as the evaluation of a priority measure F_i (i =1, ... m) from three function attributes:

- the cost Ci calculated as described in the previous section;
- the degree of importance Ii which users attribute to the function for purchasing decisions;
- the degree of satisfaction Si which users recognize in the product with respect to the function.

Importance and satisfaction attributes, expressed in an arbitrary scale (e.g. 0-10), are evaluated by interpreting the results of interviews, questionnaires or meetings with users [Fowler 1990].

As stated before, the proposed procedure is motivated by the lack of explicit relations between attributes and priority measures. These relations should be able not only to detect attribute combinations which are critical to product success, but also to suggest specific redesign actions.

On many VA cases reported in literature, it has been observed that the search for technical solutions after function analysis aims at three typical objectives: (a) increase the degree of satisfaction of a function, (b) decrease the cost of a function, (c) remove a function. Accordingly, three fuzzy sets [Cox 1994] called Fix, Cheapen and Remove have been defined. A function belongs to them if it needs to be improved to a higher satisfaction level (‘fix’), fulfilled at a lower cost (‘cheapen’) or eliminated from the product (‘remove’). Three more fuzzy sets called Costly, Important and Satisfactory, related to function attributes, have been defined. A function belongs to them if it has comparatively high values of C_i (‘costly’), I_i (‘important’) and S_i (‘satisfactory’). The following fuzzy rules apply:

$$\begin{aligned} &\text{Fix} = \text{Important} \cap \neg\text{Satisfactory} \\ &\text{Cheapen} = \text{Costly} \cap \text{Important} \qquad (4) \\ &\text{Remove} = \text{Costly} \cap \neg\text{Important} \end{aligned}$$

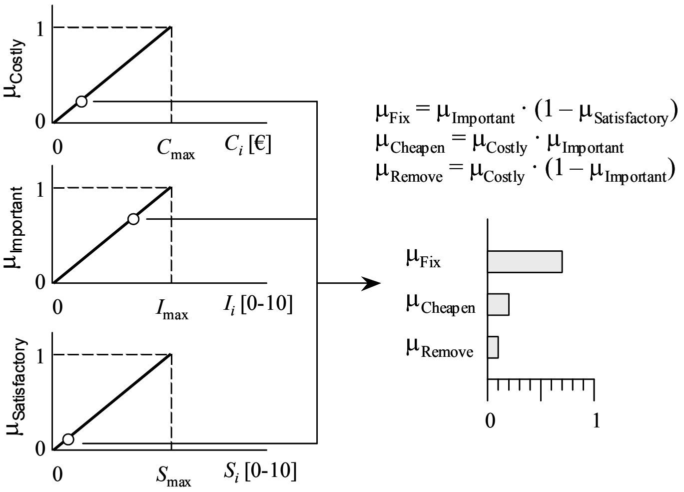

Figure 3. Fuzzy targeting procedure

Membership functions to all the above defined fuzzy sets are evaluated for each product function. Memberships $(\mu_{\text{Costly}})_i$, $(\mu_{\text{Important}})_i$ and $(\mu_{\text{Satisfactory}})_i$ are linearly calculated from normalized values of C_i, I_i and S_i. Memberships $(\mu_{\text{Fix}})_i$, $(\mu_{\text{Cheapen}})_i$ and $(\mu_{\text{Remove}})_i$, which are priority measures for the three types of redesign actions, are calculated from (4) by the product composition rule (Fig. 3).

5. Example

The proposed approach is demonstrated on a case drawn by a recent VA project involving an Italian firm. The product under study is an electromechanical assembly for point-of-sale terminals, whose redesign was suggested by the need to fix some running defects at customer sites. As illustrated in Fig. 4a, the assembly includes a thermal printer and a winding mechanism for the printed paper roll (journal). The identified hierarchy of product functions is shown in the FAST diagram of Fig. 4b.

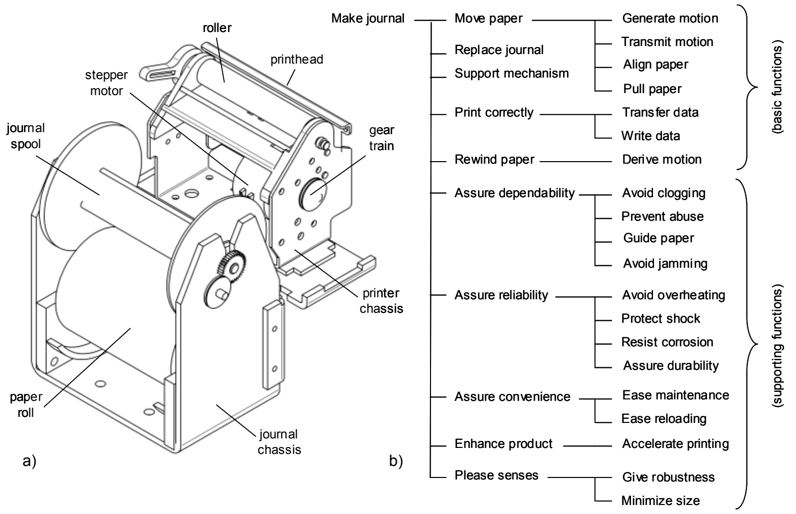

Figure 4. Test product and FAST diagram

To test the effectiveness of the simplified costing procedure, the simulation model of Fig. 2a was implemented along with two variants, which use more detailed product data to get lower dispersions of residual cost. The first one uses available part costs rather than random c_j's in step 1. The second one, in addition to that, uses available part-function relations to set nonzero a_{ij}'s in step 2. Simulation results shown Fig. 5a suggest that the costing procedure can be simplified according to a residual cost around 10%. According to part cost distribution, this means that a detailed analysis is required for 10 parts out of 29, without incurring (at a 95% confidence) an error higher than 5% on normalized function costs. Intercepts at 5% level of the three plots are in good accordance with regression results of Fig. 2b ($n = 29$, $m = 22$, $z = 3$, $\rho = 0.20$). This seems to confirm that the predictive model can readily estimate the residual cost without the need to run a simulation plan, thus obtaining fast directions on the most proper simplification degree for a function costing procedure.

Results of the proposed targeting procedure are shown in the histogram of Fig. 5b, which points out the need of priority-ranked redesign actions on the following functions:

1. avoid clogging (increase satisfaction and decrease cost);
2. assure durability (increase satisfaction);
3. ease reloading (decrease cost and, with lower priority, increase satisfaction);
4. guide paper (increase satisfaction);
5. minimize size (increase satisfaction);
6. avoid overheating (increase satisfaction);
7. avoid jamming (increase satisfaction).

In later phases of the VA, ideas on alternative ways to fulfil these functions were generated. Some of them were developed into feasible concepts, eventually selected for engineering implementation. This led to the following technical solutions:

- redesign of the gear transmission (‘avoid clogging’ function);
- changes on motor power supply and printhead control logic (‘assure durability’ function);
- consolidation of the journal spool in a single part (‘ease reloading’ function);
- better printer-spool positioning by a unified chassis (‘avoid jamming’ function).

Targeting rules proved helpful to focus redesign on critical improvements for product acceptance.

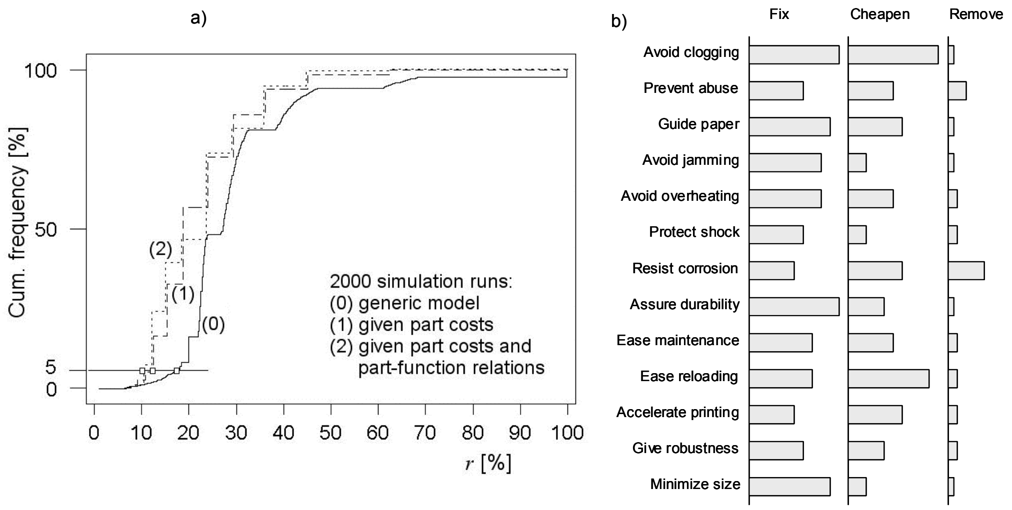

Figure 5. Simulation results and redesign priorities

6. Conclusions

The paper has described modified procedures for function costing and targeting within redesign-oriented VA projects. Their validation on a real case confirms that:

- the simplified costing procedure can allow significant time savings, due to the chance to exclude a relevant fraction of part count from function analysis;
- the simulation and the prediction model of residual cost allow to estimate this fraction for any product, and highlight the conditions allowing the highest simplification degrees;
- the fuzzy targeting procedure eases the selection of priority functions for redesign, and increases the awareness of the analyst on critical aspects of product configuration.

For these reasons, an application of the proposed solution can contribute to the objective of exploiting VA benefits in manufacturing contexts with limited engineering resources. In the same perspective, efforts will be put on the development of computer-based support tools for function analysis, with proper consideration to the task of function definition left out from the present study.

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