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A new approach for assessing function-cost correlation in product value analysis

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Abstract

The paper presents a new approach for product value analysis by combining a classical approach with a straightforward (intuitive) one and incorporating a new method of calculating (setting up) a statistical confidence interval in terms of functionality and cost. In this process, the value analysis team can observe the differences between the ideal and real function to cost ratio and easily set up a confidence interval avoiding negative effects on the overall product quality. Moreover, computing an "close to optimal state" for the function-cost ratio, results in a better understanding of the differences, thus aiding the process of generating solutions for adjusting the ratio in case of cost reduction or reallocation, integrating a new function, product reengineering or modernization.

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Keywords: value analysis; function-cost ratio, confidence interval;

1. Introduction

Product value analysis is a systematic method to improve the value of an existing product, with the help of functional analysis. The term of product value has different meanings, depending on the view point of authors: production value (referring to production costs), market value (referring to a selling price) and functional value (referring to utility). In terms of product value analysis, the specific literature refers to it as the function to cost ratio.

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A paper published by Jay C.I. & Bowen P.A. (2015) illustrates the impact of value analysis (VA) on innovation within organizations. Moreover, the paper shows that from its methods and techniques, the concept evolved under a number of different names, i.e. from value analysis (VA), value engineering (VE) to value management (VM) and even value engineering teardown (VET) or quality function deployment (QFD). Thus, showing that value analysis is broadly-based on elements and theories of function utility and cost.

Product functions refer to what a product does and some authors characterized it in a simple verb-object format (Stone, R.B. & Wood, K.L., 2000), others in a verb-noun format (Lambert, J.T., 2000) and even in a more elaborate form that include function taxonomies (Gheorghe, C.M. et al. 2013), while others propose new methods for function conceptualization in order to ease the link with the product's components (Eckert, C., 2013, Duarte, A. Y. S. et al., 2015).

SAVE International® (Society of American Value Engineers) states that, product value must be understood as the reliable performance of functions to meet customer needs at the lowest overall cost. Thus, product value analysis is the starting point to achieve an optimum balance between function and cost.

By using different methods, one can identify an "ideal state" of the function to cost ratio. To obtain the maximum value out of the existing product, the company's R&D department should adjust the ratio to obtain a proper balance between function and cost.

This perfect ratio is sometimes impossible to achieve (depending on the company's production and financial capabilities) and usually the R&D department decides to make cost concessions, trying not to affect the overall product quality.

A study conducted by Ibusuki, U. & Kaminski, P.C. (2007) shows the importance of incorporating product value analysis methodology in an automotive company and how it leads to cost reduction opportunities and product function improvements. In other words, they show how to improve a product's value by optimizing the function to cost ratio, resulting in more benefits to its customers and company profits.

Another study, conducted by Mostafaeipour, A. (2016), presents 14 creative ideas, resulted from implementing product value analysis in a construction project and how the best solution may lead to cost savings and quality improvement. Although, our paper doesn't address the issue of generating solution and decision making, however it sheds some light on the stepping stones for function to cost ratio optimization.

From this concern, our paper presents a new approach for assessing function-cost correlation in product value analysis. An important aspect of the new approach represents the confidence interval in which the function-cost ratio may vary from the "ideal state", thus making it easier for the value analysis team to take decisions without negatively affecting production costs and product functionality/utility.

2. Methodology and data

2.1. Classic methods used to assess function-cost correlation

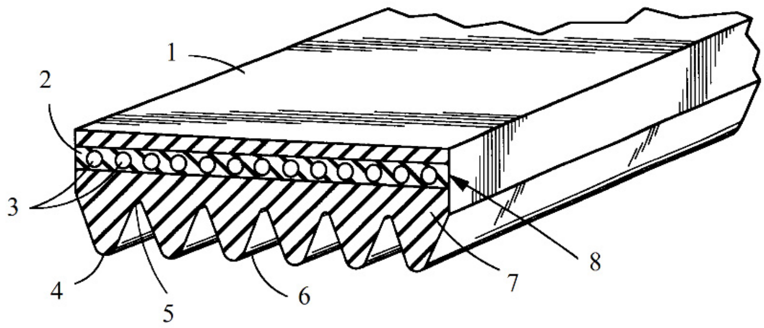
The starting point for assessing a new approach for function-cost correlation in product value analysis is to survey several existing methods. A standard approach used by several authors (Ioniţă, I., & Mănăilă, R., 2008, Chichernea F., 2014 & 2015) to analyze the function-cost correlation requires the least square method (with or without using predictors). The method presents the "ideal state" of the function-cost ratio from a statistical point of view using the real function cost. Thus, the real function costs are optimized by "bringing" them as close as possible to the linear regression model. However, the method does not specify an accepted tolerance interval in terms of function cost or functionality/utility and this might lead to a great effort in optimizing the ratio.

A more intuitive and simple method (Popa, H. L., 2003), presents an accepted tolerance interval for function costs (±2% from the ideal cost). The interval having a band strip shape, that is parallel to the "ideal state" of the function-cost ratio, is rather complicated to determine, because (in terms of function costs), it may lead to a faulty cost reallocation, i.e. a function's cost with a low importance weight may vary in its superior limit as much as one with a high importance weight, in its inferior limit.

The advantages and disadvantages in interpreting the function-cost correlation, respectively computing the confidence interval, using the two methods, and are broadly presented in subchapter 2.3.

2.2. Technical characteristics of the product

In order to present our new approach, we shall use the product “Multi-V Transmission Belt” to conduct a case study, Figure 1 showing a section view of the product’s main components and structure. The “Multi-V Transmission Belt” is a flexible and durable continuous strap (used in modern engines) which facilitates torque transmission to alternators, water pumps, fans, air conditioning compressors, power steering etc.



(1) Thin elastomer body, (2) Fluoropolymer impregnated elastomer membrane, (3) Tensile and tension elements (metal cords), (4) Apex area, (5) Trough area, (6) Micro-nervures for sheave contact, (7) Thick elastomer body – contact zone, (8) Resistance structure (2+3)

Fig. 1. Section view of the Multi-V Transmission Belt (Adapted from Burlett, D., 2009).

2.3. Function nomenclature, importance level and economic dimensioning

After collecting information from a local automotive company (technical documentation and production costs) and using the methodology mentioned above we have determined the product function nomenclature and importance level and weight (Table 1).

Table 1. Product functions nomenclature.

Function symbol	Function description	Importance level	Importance level weight
F1	Ensures torque transmission	9	0.200
F2	Friction wear resistance	7	0.156
F3	Elastic deformation resistance	5	0.111
F4	Dynamic gear load resistance	8	0.178
F5	Temperature resistance	4	0.089
F6	In use sound protection	6	0.133
F7	In use anti static protection	3	0.067
F8	Easy to install/dismount	2	0.044
F9	Product information (labels)	1	0.022
Total		45	1.00

After establishing the functions’ importance level and analysing the product from a technical, technological and economical point of view (based on information obtained from the company), we have computed the ideal costs and real function costs for the Multi-V Transmission Belt (Table 2).

Table 2. Product functions nomenclature.

Function symbol	Ideal function costs (Lei)	Ideal function costs wight	Real function costs (Lei)	Real function costs weight
F1	1.572	0.200	1.581	0.201
F2	1.223	0.156	0.853	0.109
F3	0.873	0.111	0.853	0.109
F4	1.397	0.178	0.853	0.109
F5	0.699	0.089	0.853	0.109
F6	1.048	0.133	0.783	0.100
F7	0.524	0.067	0.748	0.095
F8	0.349	0.044	0.748	0.095
F9	0.175	0.022	0.588	0.075
Total	7.860	1.00	7.860	1.00

To analyse the function-cost correlation, we used the two methods mentioned earlier in subchapter 2.1. Figure 2 presents a graphic of the function-cost correlation, in which we observe the ideal state of the ratio and the real function costs, based on the two methods mentioned earlier.

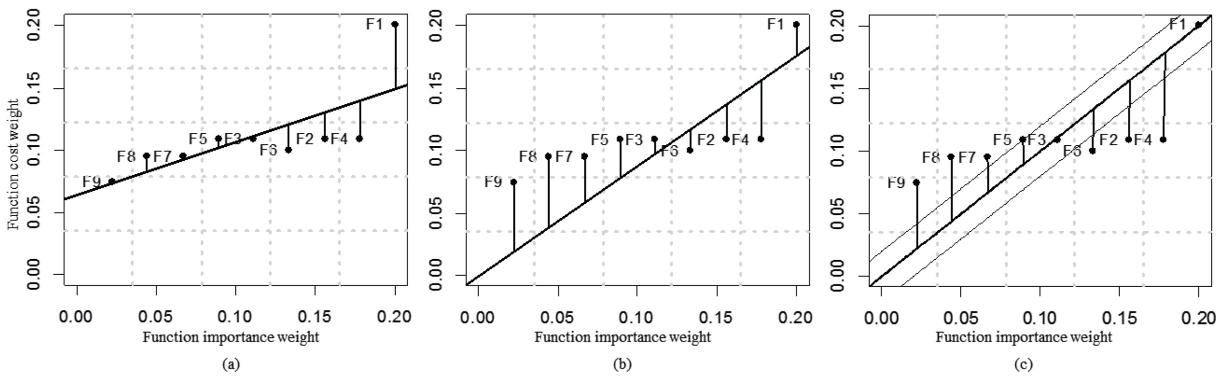


Fig. 2. Function-cost correlation for the Multi-V Transmission Belt.

Based on the two methods mentioned earlier, we observe different perception for the function-cost correlation:

- From Figure 2 (a), we can observe the linear regression model with an intercept (y=a+b*x) and it doesn’t pass through the axis origin, resulting that F1, F5 and F8 need cost reduction actions, while F2, F4 and F6, need to be improved. The disadvantage of this linear regression model is the lack of statistical support, because the coefficient of determination is only 50% and the p-values corresponding to the coefficients a and b are above 0.01.
- From Figure 2 (b), we can observe the linear regression model without an intercept (y=b*x), that passes through the axis origin, resulting that F1, F3, F5, F7, F8 and F9 need cost reduction actions, while F2, F4 and F6, need to be improved. The advantage of this regression model is the statistical support, because the coefficient of determination is 89% and the p-value of the coefficient b is less than 0.001, being a better representation for the function-cost correlation.
- From Figure 2 (c), we observe the ideal state model (y=x), that that passes through the axis origin and the confidence interval set at ±2% from the ideal cost (not having a statistical justification), resulting that F7, F8 and F9 need cost reduction actions, while F2, F4 and F6, need to be improved.

A confidence interval can and will help the value analysis team to optimize the function-cost ratio; i.e. if a function cost is above the ideal state, it’s recommended to find solutions to reduce the cost or if a function cost is under the ideal state, it’s recommended to find solutions to increase the utility of the function (usually by adding costs). In both cases the general objective is to ensure that the function performance will meet customer needs at the lowest overall cost. On a side note, to create the confidence interval, the value analysis team has to take in consideration the company's production and financial capabilities.

2.4. The new approach in assessing function-cost correlation

In order to create a confidence interval, for this specific case, first we verified the assumption of normal distribution for differences by calculating the mean value and dispersion. If the dispersion σ^2 differs from the different value segments for Y, it results in a property called homoscedasticity.

The verification of this property is made by taking on the abscissa and its order, the relatively stable distribution of its values on one side and the other side the OX axis, thus in a limited band, signalling the constant of the dispersion σ^2 of differences. A way to check this property is to use the F-test for which the value (is ordered in relation to the y_i values) is divided into at least two segments, creating the following null hypothesis:

H_0 = "the difference between the dispersions of the two segments is insignificant"

We mention that the rejection of the null hypothesis ($F_{calc} > F_{tab}$) means that the residual values are heterogeneous (unequally distributed) which leads to the loss of some estimators' qualities. The loss of precision and predictions on the evolution of the variable-effect results in a loss of accuracy (loss of consistency and coherency).

A more sophisticated test for homogeneity dispersion, is the Bartlett test (NIST/SEMATECH, 2003). Reducing or even avoiding the consequences of heterogeneity is accomplished by segmenting the sample into homogeneous sub-selections using the level of factors, followed by a retention pattern for each segment. The Bartlett's test is defined for the following null hypothesis (H_0) and respectively the alternative hypothesis (H_a):

$$H_0: \sigma_1^2 = \sigma_2^2 = \cdots = \sigma_k^2 \quad (1)$$

$$H_a: \sigma_i^2 \neq \sigma_j^2 \text{ ; for at least one pair (i, j)} \quad (2)$$

The Bartlett test is designed to test the equality of variances across groups, against the alternative that variances are unequal for at least two groups. The mathematical expression for the test statistics is:

$$T = \frac{(N-k)\ln(S_p^2) - \sum_{i=1}^{k}(N_i - k)\ln(S_i^2)}{1 + \left(1/(3(k-1))\right)\left(\left(\sum_{i=1}^{k} 1/(N_i - 1)\right) - 1/(N-k)\right)} \quad (3)$$

where:

S_i^2 is the variance of the ith group,
N is the total sample size,
N_i is the sample size of the ith group,
k is the number of groups,
S_p^2 is the pooled variance.

The pooled variance is a weighted average of the group variances and is defined as:

$$S_p^2 = \sum_{i=1}^{k}(N_i - 1)S_i^2/(N - k) \quad (4)$$

The variance is judged to be unequal if

$$T > \chi 2^{1-\alpha,\ k-1} \quad (5)$$

Secondly, we apply the Bartlett test to verify homoscedasticity, for the differences (denoted with er_i) between the ideal and real function costs:

$$er_i = y_i - x_i\, , I = 1, 2, \cdots, 9 \tag{6}$$

These 9 differences are divided into three groups and the variance is calculated for each group, results can be seen in Table 3.

Table 3. Groups and calculated variance.

Group	Group 1 (er_1)	Group 2 (er_2)	Group 3 (er_3)
Variance	0.000193000	0.001281333	0.008839091

From Table 3 we can observe that the variance differs from one group to another, so the homoscedasticity hypothesis it seems that it cannot be sustained. The "boxplot" graph (Figure 3) shows a different statistical value for the three groups (the last group being the extreme value "outlier").

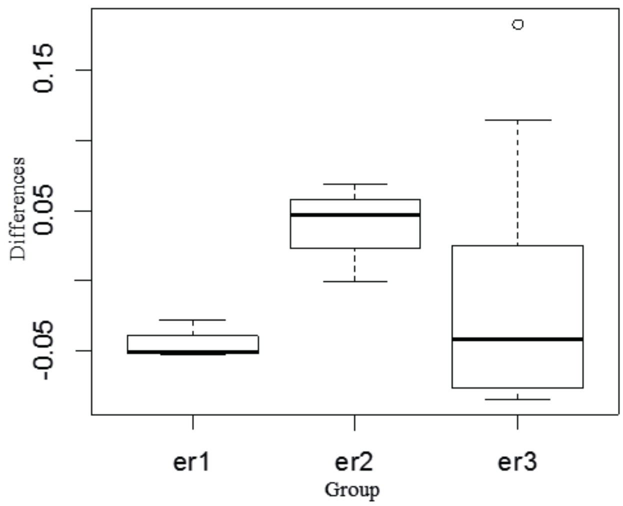


Fig. 3. The boxplot graph of differences.

Next, we compute the Bartlett test for homogeneity of variance (homoscedasticity). The computed value (with a p-value = 0.04783) of this test is 6.0802, which is greater than the quantile $(\chi^2)^{0.99,\, 2}$ therefore, the hypothesis of homoscedasticity is rejected.

Using the computed values, we can create a confidence interval for our specific case. Confidence limits for the mean are an interval estimates for the mean (Snedecor, G.W. & Cochran, W.G., 1989). Interval estimates are often desirable because the estimates of the mean vary from sample to sample. Instead of a single estimate for the mean, a confidence interval generates a lower and upper limit for the mean.

Interval estimates give an indication of how much uncertainty there is in an estimate of the true mean. The narrower the interval, the more precise is the estimate.

Thus, the interval computed from a given sample either contains the true mean or it does not. Instead, the level of confidence is associated with the method of calculating the interval. A confidence coefficient is simply the proportion of samples of a given size that may be expected to contain the true mean.

Confidence limits are defined as follows (Negrea, R., 2006):

$$\bar{Y} = \pm\, t_{1-\alpha/2,\ N-1} \frac{S}{\sqrt{N}} \quad (7)$$

where,

$\bar{Y}$ is the sample mean,
S is the sample standard deviation,
N is the sample size,
α is the desired significance level,
$t_{1-\alpha/2,\ N-1}$ is the quantile of the T (student) distribution.

To test whether the population mean has a specific value, μ_0, against the two-sided alternative that it does not have a value μ_0, the confidence interval is converted to hypothesis-test form. The test is a one-sample t-test, and it is defined as follows:

$$T = (\bar{Y} - \mu_0) \frac{S}{\sqrt{N}} \quad (8)$$

After computing the confidence interval with samples from the first and last group, we observe the following values (Table 4):

Table 4. Confidence interval limits

Group	T-test value	Lower limit	Upper limit
Group 1 (er_1)	13.25	0.05964898	0.11701768
Group 3 (er_3)	4.45	0.00771865	0.27161468

We can observe differences from the upper and lower limits for the T-test of these two groups, therefore a confidence region should not be a band strip, and more naturally should be a "V" shaped strip (Figure 4). Also, we can observe that using this confidence interval only two product functions need cost reductions (F8 and F9), while F2, F4 and F6 need to be improved.

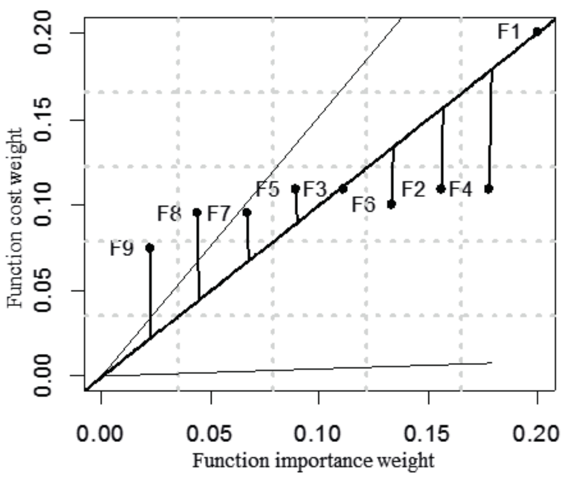


Fig. 4. Confidence interval.

3. Conclusions

The main aim of our study was to test our new approach for assessing the function-cost correlation, with the emphasis on the "V" shaped confidence interval. Thus, in our paper we presented a method to create a confidence interval, which may be used by a value analysis team to improve the function-cost ratio.

In this context, we observed that the linear regression model is ignoring the ideal state of the function-cost ratio, while the band strip confidence interval accepts minor cost differences, both methods leading to great efforts in the attempt of improving the function-cost ratio.

The new approach shows that only 2 out of 9 product functions costs need major reductions (F8 and F9) in order to improve the ratio. From this point of view the "V" shaped confidence interval makes it easier to identify where cost reduction should be done, resulting in no faulty function cost allocation or reallocation. On the other hand, the trust interval helps the value analysis team to better understand the differences between the ideal state and an accepted state and how to reduce or improve them.

The new approach uses the existing functions of the Multi-V Transmission Belt, thereby further analysis is required to understand how new added functions (resulted from market research) will influence the function-cost correlation and its confidence interval. Moreover, the confidence interval is computed form a statistical point of view and future research is needed to corroborate it to the company's production and financial capabilities.

Further research is focused on a generalized model for the confidence interval that can be applied for any industry, product type, company's production or financial capabilities, leading to a better understanding of the need and advantages of using the value analysis methodology.

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