Extended Model for Integrated Value Engineering

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Abstract

Manufacturing firms have to design products for global competitive markets that provide a distinct cost-value-ratio. Literature provides approaches like target costing and value engineering to counter this challenge from different angels. Combining benefits and summarize any immediate information during the application of both approaches within a comprehensive model this paper presents a model for integrated value engineering. This model is extended by the consideration of manufacturing processes as well as supply chain networks, as those factors emerge as drivers for costs and values in manufacturing firms, while the original model already considers requirements, functions and physical components of a product.

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Value Engineering, Target Costing, Comprehensive Model, System Engineering, Multiple-Domain-Matrix

1. Introduction

Manufacturing firms operate in global competitive markets that transformed from a sellers’ to a buyers’ mark.1,2 To prevail in this competition, manufacturing firms have to design products with lower costs and enhanced value to the customer.3 This challenge expresses a reduction of the cost-value-ratio of a product. Target costing and value engineering are applied to approach this ratio from different perspectives as target costing focuses on the achievement of market prices through the deduction and enforcement of allowable costs within the development of a product 4, while value engineering aspires the increase of value through either an increase in functionality or a

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reduction of resources (e.g. costs). In the last decades manufacturing firms rethought their concept of cooperation and concentrated on their core competences to cope with the subsequent fierce competition. Firms transferred large shares of their value creation in terms of development and production to their supply chain network. As a result, manufacturing either in-house or at suppliers emerge as further drivers for costs or values of a product that need to be considered explicitly by approaches aiming for a decrease of the cost-value-ratio.

1.1. Target costing

Target costing (TC) is a technique for the management of a manufacturing firm’s future profits that focuses on costs within the product development process. In its essence TC describes the deduction of allowable cost for a product based on the deviation of an attainable selling price and the required profit margin. Literature refers to this market orientation as market-driven costing or reverse costing. Lockamy and Smith elaborate that customer requirements are the major cost driver in manufacturing firms. Moreover, they state that TC is not necessarily focusing on costs. Costs result from processes that are performed within the manufacturing firms itself or within its supply chain network. TC supports the alignment of the entire value chain towards the objective to eliminate waste, excess and unevenness. Thereby, TC follows two costing sections; product- and component-level. Within the product-level TC product designers are encouraged to focus on the costs of the product. The component-level TC focused on suppliers that are claimed to design and manufacture components in accordance to costs, quality and functionality.

In order to implement TC in a manufacturing firm and to determine the target costs for a product Ibusuki and Kaminski propose a process that is presented in the following (Fig. 1). The first step (TC-1) focuses on the reorientation of the culture and attitudes within a firm towards market-driven pricing as basis for the deduction of allowable costs for a product. The second step (TC-2) describes the establishment of a market-driven target price that is derived from various market factors (e.g. market position, competitors …). Based on the target price the target costs are determined within the next step (TC-3). Thereby, the target costs are calculated. Another factor besides required profit margins of the firm is taxes and indirect costs. TC-4 describes the balancing between target costs and requirements. The latter are major cost drivers. A comprehensive understanding of requirements through methods (e.g. conjoint analysis, quality function deployment …) is essential for the conclusion of sound target costs. The fifth step (TC-5) deals with the implementation of TC through establishing a corresponding process including activities to support target costs and a team-based organization to integrate other disciplines (e.g. marketing, manufacturing, procurement …). The next step (TC-6) focuses on the generation of ideas and the analysis of alternatives for potential cost reductions. During TC-7 a product cost model is composed to support the decision making. Thereby, the model provides an overview of product costs from different perspectives. This requires a comprehensive model in order to address the different alternatives for cost reductions. The eighth step (TC-8) suggests the use of tools like design-for-X to reduce costs. As a major share of a products’ cost relate to indirect costs TC-9 suggests their reduction. The last step (TC-10) focuses on the implementation of TC to the core of the cooperation by an evaluation of the measures. Thereby, the current and estimated costs of a product are continuously monitored against its target costs during the project.

Fig. 1. Process of target costing (Based on [12])
1.2. Value engineering

Value Engineering (VE) is a systematic process to achieve “the essential functions at the lowest lifecycle costs consistent with required performance, reliability, availability, quality, and safety” for a certain product. VE is not focusing on cost reduction, but on an increased value. It is a function-oriented approach that illustrates the ratio between “what you get” (function) and “what it costs” (resource) as definition of value. Thereby, VE assumes that all participating disciplines share the same understanding of functions provided by the product. Green argues that VE features an assessment of different design alternatives based on costs only, as it is assuming that all alternatives provide the same level of functionality to a customer. Based on this assumption – the function is equal for all alternatives – a value increase may be realized through a reduction in cost (resources). Therefore, VE is different from the often equally used terminology value management, which is more concerned “to develop a common understanding of the design problem, identify explicitly the design objectives, and synthetize a group consensus about the comparative merits of alternative courses of action.” Besides improving the value of a product, VE provides other benefits like reduce risk, improve quality, understand customer requirements of a knowledge transfer in multi-project settings.

The Handbook on Systems Engineering provides a multi-step process for VE presented in the following (Fig. 2). A preliminary step (VE-0) is the preparation and planning of the scope. Thereby, restrictions and objectives of the VE effort are elaborated. The first step (VE-1) describes the information acquisition in order to clarify on the challenges and objectives. Therefore, relevant background information is gathered and customer requirements are derived. The next step (VE-2) features a functional analysis of the product based on essential information (e.g. drawings, costs, quantities …). Within this step functions are defined and described by an active verb and measurable noun. Against this background, the relevance of functions is assessed, which may be supported by numerous techniques provided by literature. Those techniques cover function analysis system technique (FAST), pareto-analysis, cost-to-function analysis and further more. This step ends with a clearly defined and documented number of areas that provide the greatest opportunity for improvements. VE-3 focuses on the generation of ideas for the accomplishment of functions by different alternative courses of action. Thereby, creativity techniques (e.g. brainstorming, brainwriting …) are employed. Based on the derived ideas, the fourth step (VE-4) focuses on the discussion and assessment of the ideas or even alternatives with a suitable evaluation technique (e.g. score evaluation). VE-5 focuses on the development of ideas to sound alternatives that are presented to decision makers. Then again, the alternatives of VE-4 are further detailed to a proposal. The last step (VE-6) deals with the presentation and implementation of the conducted alternatives. In addition, Webb points out the importance to check the target achievement.

<table>
<thead>
<tr>
<th>VE-0 Preparation/ Planning</th>
<th>VE-1 Information gathering</th>
<th>VE-2 Function Analysis</th>
<th>VE-3 Creativity</th>
<th>VE-4 Evaluation</th>
<th>VE-5 Development</th>
<th>VE-6 Presentation/ Implementation</th>
</tr>
</thead>
</table>

Fig. 2. Process of value engineering (Based on [5])

1.3. Research objective

TC and VE are used in manufacturing firms to advance their competitive ability by improving the cost-value-ratio by either reducing costs or improving value. Both approaches introduce multiple-step processes including numerous methods that provide insights in the costs or values of a product. Firms have to be aware of the product represented by its functions and physical components that need to meet the customer requirements. Besides, manufacturers and suppliers emerge as drivers for the products’ cost-value-ratio as manufacturing processes require higher levels of expertise and get more distributed within a supply chain network. These various influencing factors challenge manufacturing firms and require a comprehensive model that is provided by neither TC nor VE. As a result, the objective of this paper is to provide a model based on the original model for integrated value engineering (IVE) by Maisenbacher et al., which is extended by manufacturing processes and the supply chain network.
2. Research Methodology

Providing the fundamentals for the comprehensive model, this paper includes a literature review on approaches for TC and VE. Both approaches lack a comprehensive model so that the paper at hand employee a Multiple-Domain-Matrix (MDM) to describe the relevant domains and dependencies for VE from a system perspective. Thereby, the product is described by requirements, functions and components accompanied by a representation of manufacturing processes as well as supply chain networks within the comprehensive model. MDMs are applied in the field of systems engineering and support the handling of complex systems. The comprehensive model is evaluated in terms of internal validity through a case study from academia (section 4). Moreover, its operability is evaluated through two case studies within the development and manufacturing system of engines and gas turbines that are not presented due to the confidentiality agreement with the case study providing firms.

3. Extended Model for Integrated Value Engineering

3.1. Original Model for Integrated Value Engineering

The original model for IVE combines VE and TC to an integrated approach with a MDM as fundamental representation in its center. Thereby, the product is described through three domains: requirements, functions and components. These essential domains characterize the major stages of a product development process, starting with the deduction of company-internal and -external requirements, their transformation into product functions and their physical implementation through components. These domains are interlinked through dependencies, which describe their interaction. Functions fulfill requirements; likewise, functions are fulfilled by components providing certain functionalities. The MDM arranges these domains and their dependencies, while serving as system model. Moreover, the MDM maps the corresponding cost information of the product (target- and current costs) within these three domains in accordance to the approach of TC.

Besides the system model, Maisenbacher et al. provides an eight-step procedure to perform a value analysis and derive potentials to increase the cost-value-ratio of a product. The first three steps (A-C) deal with the definition of elements within the domains describing the product. Within the following two steps (D-E) target- and current costs are derived. The procedure features the deduction of correlations (F) that support the transfers of cost information (target and current) within one domain to the others. This allows the comparison of costs (target and current) within the different domains (G) as basis for the deduction of measures for the product improvement (H).

3.2. Extended Model for Integrated Value Engineering – Comprehensive System Model

The extended model for IVE features the domains requirements, functions and components that are presented in the original model for IVE. Thereby, the domain of components is further detailed in order to gain a deeper insight in the distribution of costs and values. Christopher et al. propose to take a supply chain network perspective on costs. Based on the concept of make-or-buy decisions, a component is either manufactured by the firm in-house (make-decision) or purchased from a supplier (buy-decision). Manufacturing firms apply both alternatives to provide products to their customers. Unless components are manufactured in-house or purchased from suppliers certain (final) assembly processes are required to join the components together to receive the ultimate product. Besides costs and values arising from the purchase of components (buy-decision), manufacturing and preliminary assembly processes required for the components (make-decision) represent cost and value drivers for manufacturing firm as well as any final assembly processes required for the ultimate product. As a result, the domain of components (including its values and costs) is divided to the domains of final assembly processes (assembly), manufacturing processes (manufacturing) and purchased parts (suppliers). Fig. 3 presents these three domains in addition to the product representation (requirements, functions and components) as well as the comparison of their current and target costs. Furthermore, Fig. 3 illustrates the dependencies between the six different domains within the MDM. Thereby components are either supplied by suppliers or processed by a certain manufacturing process. In addition components are processed by certain final assembly processes that are required for joining the components together to receive the ultimate product. While the three domains requirements, functions
and components add up to a 100% of costs of the ultimate product, the domains assembly, manufacturing and suppliers together represent these 100% of costs for components. This assumes that costs for suppliers represent the parts price including the costs for manufacturing, transportation, storage, overheads and others so that no additional costs incur at the manufacturing firm.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Function</th>
<th>Component</th>
<th>Assembly</th>
<th>Manufacturing</th>
<th>Supplier</th>
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<tbody>
<tr>
<td>R</td>
<td>F</td>
<td>C</td>
<td>A</td>
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<td>S</td>
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<td>Function</td>
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<td>F function fulfills requirement</td>
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<td>Component</td>
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<td>component fulfills function</td>
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<td>Assembly</td>
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<td>assembly processes component</td>
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<td>Manufacturing</td>
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<td>manufacturing processes component</td>
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<td>Supplier</td>
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<tr>
<td>supplier supplies component</td>
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Fig. 3. System model (Based on [16])

3.3. Extended Model for Integrated Value Engineering – Procedural Model

The procedural model consists of five major phases with various activities (Fig. 4). A preliminary phase (IVE-0) sets the scope of the VE initiative. This phase defines objectives and identifies relevant stakeholders for the initiative. Furthermore, this phase provides a planning of the required activities within the other phases and determines the shape of the system model with its domains and their relations. The first phase describes the information acquisition (IVE-A) of the relevant information on elements within the domains and dependencies between those elements in terms of the type of relation set by the system model (IVE-0). Table 1 illustrates the activities of IVE-A and the corresponding information that is acquired within that phase based on the system model (Fig. 3) in addition to the information that is already included in the original model for IVE presented by Maisenbacher et al. 16.

Table 1. Activities and acquired information of IVE-A

<table>
<thead>
<tr>
<th>Information acquisition activity</th>
<th>Acquired information</th>
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<tbody>
<tr>
<td>Determine suppliers for the product</td>
<td>Elements within the domain supplier (assigned suppliers)</td>
</tr>
<tr>
<td>Define manufacturing processes of the product</td>
<td>Elements within the domain manufacturing (manufacturing processes)</td>
</tr>
<tr>
<td>Identify final assembly processes of the product</td>
<td>Elements within the domain assembly (assembly processes)</td>
</tr>
<tr>
<td>Determine suppliers for components</td>
<td>Dependency: “Supplier supplies component”</td>
</tr>
<tr>
<td>Assign manufacturing processes to components</td>
<td>Dependency: “Manufacturing processes component”</td>
</tr>
<tr>
<td>Assign final assembly processes to components</td>
<td>Dependency: “Assembly processes component”</td>
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</tbody>
</table>

Besides those activities a major effort of this phase is assigned to the acquisition of the current and target costs of the three domains assembly, manufacturing and supplier. IVE-B focuses on the information analysis. Thereby, the major activity is a comparison between the current and target costs within the six domains of the system model to derive cost or value potentials. In order to derive those potentials a wide range of methods for the analysis is provided by literature like functional analysis 5, value stream mapping 22, supply chain analysis 23 or structural analysis 17 among others. The third phase (IVE-C) concentrates on the implementation of the identified potentials. Therefore, this phase includes activities to derive different alternatives for the implementation of the potentials using creativity techniques. Another activity within IVE-C focuses on the assessment of the alternatives to enable a proper
decision. The last phase (IVE-D) is dedicated to the controlling of the VE initiative and therefore is not limited to the controlling of its final results but on the continuous comparison of the planning against the actual implementation. As a result, this phase is performed simultaneously to the other phases (IVE-A to IVE-C) and ensures the achievement of the objectives. Fig. 4 summarizes the presented phases.

![Fig.4. Procedure for the IVE initiatives](image)

4. Academic case study

The original model for IVE was applied on industrial use cases of industrial gas engines for power generation and thereby provided enough details for the deduction of initial potentials for improvement. However, this evaluation revealed the demand of a further and a more detailed analysis that is aspired by the extended model for IVE. The major shortcoming of the original model was the lacking consideration of component costs breakdown from the perspective of assembly, manufacturing and the supply chain network, which is explicitly addressed by the extension of the paper at hand. The extended model for IVE was applied to a cylinder head on an industrial fuel engine. The model revealed various potentials for improvement that were discussed in a team of experts on VE, TC and cost analytics. Thereby, the application of the model and the conducted potentials has been assessed as highly relevant and beneficial for the case study providing manufacturing firm. However, due to the confidential agreements with the manufacturing firm, this paper is not providing cost or value information of the fuel engine.

In order to give insights in the application of the extended model for IVE and its possible analysis results a case study from academia is presented in Fig 5.

![Fig. 5. System model of the academic case study](image)
It is based on a product with three different components (C.1, C.2 and C.3). These components fulfill four functions (F.1, F.2, F.3 and F.4) that realize three requirements (R.1, R.2 and R.3). The components are processed out of two supplier parts (S.1 and S.2), four manufacturing processes (M.1, M.2, M.3 and M.4) and three assembly processes (A.1, A.2 and A.3). The elements and their relations are illustrated in Fig. 5. Equally to the top-down approach used for the original model for IVE the target costs of the requirements are derived according to TC from a market analysis. The target costs are then top-down assigned to the other domains. The matrix “function fulfills requirement” indicates the correlations between functions and requirements in terms of which function fulfills which percentage of a requirement. This matrix divides the target costs from requirements to functions. Afterwards the target costs are assigned to components, assembly, manufacturing and suppliers. The required matrices for this operation are not illustrated in Fig. 5, but can be taken from Maisenbacher et al.16.

The bottom-up calculation of current costs starts in the extended model for IVE with the domains assembly, manufacturing and suppliers that are assigned to components. Fig. 5 represents the correlations between these domains and the components. For example C.1 requires two manufacturing processes (M.1 and M.2) as well as the assembly process A.1. Each element of the domains assembly, manufacturing and suppliers has a current cost. These costs are assigned to the components by the correlations shown in Fig. 5. A special case is demonstrated with assembly process A.3 that is the final assembly process combining the three independent components to the ultimate product. Its current cost is assigned to each component. From the components domain the current costs are bottom-up assigned to functions and requirements similarly to the top-down calculation of the target costs. The relevant matrices for that operation are illustrated in Fig. 5 (deep grey). For example F.3 receives 20 % of the current costs of C.1 and C.3 and 33,4 % of the current costs of C.2. This means that the current costs of F.3 are 85€, which are calculated as follows: 152€ • 20% + 98€ • 33,4 % + 110€ • 20% = 85€. Moreover Fig. 5 shows the total current and target costs of the different domains. As assembly, manufacturing and suppliers are not representing the entire product, only their summation equals the cost of the entire product (see component, function or requirement).

The comparison between target and current costs of the product is shown in Fig. 5 on the right side. The absolute values indicate the difference between current and target costs. A positive value means higher current costs as target costs for an element which defines a potential for cost reduction or a potential for adding value in the corresponding domains. These potentials can be displayed in a portfolio of target over current costs for the elements within every single domain. This includes requirements, functions, components as well as the added elements of the domains assembly, manufacturing and suppliers. All elements over the bisecting angle have higher current costs than target costs. Furthermore, the distance from the angle indicates the relative potential for cost reduction or value generation; higher distance reveals greater potentials. Another indication is provided by the distance of the elements from the point of origin; higher distances represent greater cost values of the elements and therefore approximately higher absolute values to be achieved with a cost reduction.

In this use case optimization potentials are deduced in the domain components that are traced back to elements within assembly, manufacturing and suppliers. The cost comparison in the domain component reveals all current component costs that are above their targets. Especially C.3 is double its target costs. As C.3 bases on the previous processes M.3, M.4, A.2, the supplier part S.2 and partly requires the assembly process A.3, these five elements can be analyzed for a particular cost reduction. The costs for M.3 are lower than its target, which excludes it from any further investigation. A.2 and M.4 have equal cost optimization potential of 8€ each. A.3 is required for each component, so besides the potential of 11€ for C.3 a cost reduction will also affect the other two components. However, the best starting point for optimization of C.3 is the supplier part S.2. Its costs exceed its target and thereby its customer value by almost 150% or 18€. Thereby, three generic approaches can be pursued by the manufacturing firm that includes a) a reduction in the parts price at suppliers, b) a switch to an in-house production of the component or c) an increase in the features of the component extending its value. These approaches may lead to various measures of manufacturing firms which are not focused by the paper at hand. Another example is C.1. It only offers small potentials of 4€, but this is only as A.1 is 16€ and M.2 is 6€ under its target. This covers M.1 which represents 24€ over its target. An optimization of the manufacturing process M.1 seems promising. Equally potentials can be revealed in the domains function and requirement (see 16).
5. Summary and Outlook

Due to global market competition manufacturing firms are forced to increase the value of their products and to reduce costs at the same time. To support the value and cost optimization of products this paper gives an overview of the established approaches within this field through TC and VE. Moreover, this paper presents an extended model for IVE which combines TC and VE in a comprehensive system model for engineer the cost-value-ratio of products. The extended model expands the original model for IVE and its product centered domains requirements, functions and components by three domains assembly, manufacturing and supplier that provide further information on the components of a product. A procedural model is added to allow practitioners an easier and predefined application of the extended model for IVE. The model supports a systematic procedure for firms to analyze the cost-value-ratio of their products. Results are illustrated in a comprehensive model and potentials to increase the products value can be discussed in and between all domains. Especially the traceability of potentials in the components domain and therewith in the underlying domains assembly, manufacturing and supplier are highlighted in this paper. An exemplary use case from academia illustrates the applicability of the model with similar results as drawn from industrial applications. For further research the authors suggest to focus on the additional features of the model for IVE. These features cover the use of further analysis criteria for matrix-based models or the deduction of indirect dependencies within the matrix to derive further information of the system, which exceed the direct acquired information. Furthermore, additional applications like the comparison and cost optimization of different product variants are steps of future research. The application of the model to more industrial cases promises to reveal further potentials to improve the model for IVE.

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