Value Engineering as a Specialty for Systems Engineering: Exploring Opportunities

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ABSTRACT

Value Engineering is a so-called specialty engineering activity within Systems Engineering according to the INCOSE Systems Engineering Handbook [INCOSE, 2015], but what makes Value Engineering a 'specialty,' and what can it offer Systems Engineers? In this article three Value Engineering concepts are described, which are the pillars of Value Engineering: 1) the definition of value, 2) the use of multi-disciplinary workshops, and 3) the application of function diagramming with the FAST method. Each of these concepts is explained and ideas are put forward how to incorporate them in more commonly used Systems Engineering processes. Our findings show that Systems Engineering and Value Engineering are not mutually exclusive, but offer outstanding concepts to improve designers' goals. With this article, we hope to inspire the Systems Engineering and Value Engineering communities to further explore and experiment together.

INTRODUCTION

Value Engineering is a design method to deliver engineered solutions that fulfill the needs of the client and involved stakeholders at the right costs. It helps to clarify the subjective perception of value, as perceived by clients and designers, and uses processes and tools that can add value in a Systems Engineering environment. Value Engineering uses a structured process, team-based engineering activities, analytical reviews of functions, and creative techniques to improve value. For example, by improving solutions that are underperforming their intended functions, or that perform well enough, but simply cost too much.

The three Value Engineering concepts that we explore in this article are: 1) the definition of value, 2) the use of the Value Engineering workshop, and 3) the function analysis with the FAST method. Each of these concepts is explained and ideas are put forward how to incorporate them in more commonly used Systems Engineering processes. To validate our ideas on how to incorporate the value concepts in a Systems Engineering context, we conducted a small survey among systems engineers. We first explained the Value Engineering concepts during a meeting of the INCOSE Netherlands chapter. Then, we conducted a workshop where Systems Engineering practitioners could experience the concepts. Finally, we surveyed their perceptions and opinions on the possibilities to include the value concepts within their Systems Engineering practices. Overall, 21 people familiar with Systems Engineering for about 10 years on average, filled out the survey.

With this article, we aim to inspire Systems Engineering practitioners to include the value concepts in their daily work, their thinking, and their creations. For the Systems Engineering community at large, we aim to stimulate further exploration and experimentation of the value concept in projects and to investigate further application as a joint effort by INCOSE and the Value Engineering communities worldwide.

THE DEFINITION OF VALUE

Value is defined as a simple equation, although notations vary a little: Value = Function/Cost (SAVE International, 2015), or as Value = Needs/Resources, or as Value = (Function+Performance)/Costs (European Standard EN 12973:2000). In his work *Techniques of Value Analysis and Engineering*, founding father of Value Engineering, Lawrence Miles (Miles, 1962), included the concept of function as a component of value and underlined that value is established by the customer's (or the user's) needs and requirements. In a VE-context, functions are formulated by a 'verb' + 'noun' (emit light), and state *what the system should do*. Performance defines *how well the function should perform* (300 lumen, during 24 hour, with 0,5 W energy consumption). This principle has resulted in the definition of value as it is used today, stating that customer value is about balancing functional performance with the resources necessary to achieve this performance.

The value equations show that the value of a system can be improved by modifying the required resources throughout the system life-cycle and by adding functional performance that fulfills or exceeds the expected performance of the customer.

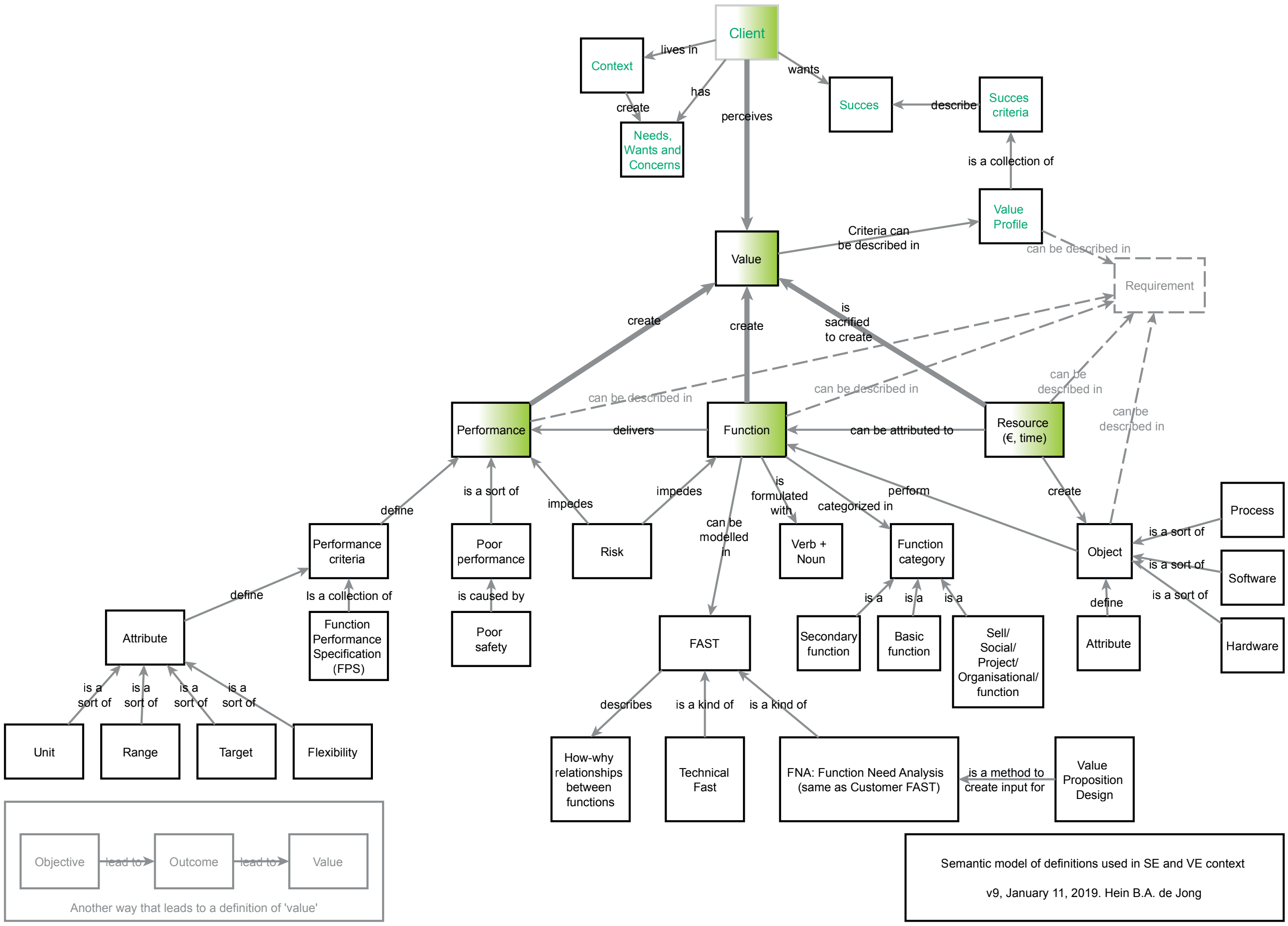

Figure 1. Value Engineering semantic model

However, value is not determined objectively: it is always subjectively related to the customer and other stakeholders, who each have their own perception of value. It therefore is not only achieved through technical engineering, but also through integrating social processes to discover the true nature of value in a given context. Although the value concept might seem rather obvious, in many projects, customer value is biased and distorted. Robert Stewart [Stewart, 2010] mentions nine reasons why an organization's effort may result in less than optimal value:

1. Focus on internal value rather than customer value
2. Honest wrong beliefs
3. Habits and attitudes
4. Fixation with previous design concepts
5. Incorrect assumptions based on poor information
6. Incomplete, poorly communicated or even lack of consensus in project scope
7. Changes in customer requirements and needs (over time / situational)
8. Outdated (technical) design standards, changing technology
9. Temporary circumstances.

How to add 'value thinking' into more common Systems Engineering activities? We further explore that in the themes 'All cost is for function,' 'trade-off analysis and value criteria,' and 'value related to time.'

All cost is for function

From the value engineers' mantra 'all cost is for function' follows that everything that costs money must be related to functions. Performances, needs, costs, concerns, outcomes, resources, wishes, and capabilities should be directly related to a function, or be described as a function itself. What might look like a semantic discussion, is in fact the effort to put information in the best place to enable design activities.

In the Value Engineering semantic model shown in Figure 1, types of information are related to each other. Note the multiple links between functions, resources, function, performance, and value. There are probably no objectives or outcomes that cannot be translated or related to the functional level. Engineers need that functional level to understand the system and to design alternatives. Also here, functions are the backbone for all other related aspects of a system, which implies that Value Engineering is very much a Systems Engineering activity.

Trade-off analyses and 'value' criteria

Considering the semantic model, it can be observed that the *performance* criteria are different from the *value* criteria. Function performance criteria, are based on the system itself and define when the system works well from the perspective of the engineering designer. The function performance criteria are specified in the well-known Function Performance Specification (FPS). Value criteria, however, are outcome related and define when the system is a success from the perspective of the client. These value criteria are stated in a so-called Value Profile. The key issue here is that the function performance criteria *do not necessarily* fully represent the needs of the customer as stated in the Value Profile. The translation from the Value Profile to the FPS often happens implicitly in the minds of engineers, but in the context of Value Engineering that should be explicitly validated by the client.

A possibility to include the Value Profile more explicitly in a Systems Engineering context, could be to include the value criteria in trade-off analyses. Adding the value criteria to trade-off analyses does not only focus on a system that does what it is engineered to do, but it also makes explicit what creates value for the customer. How often does it happen that the customer has requirements that do not add up to his most valued outcomes? And how difficult is it for the engineer to change those requirements! And how often does it occur that a system is beautifully engineered, while the client doesn't value it as such? The value profile and FPS tools can help.

Value related to time

Although the Value Profile can be very helpful, it is a challenge to design and engineer systems when the value perceptions of the clients change, for example, when influenced by age, fashion, information, distance, perceptions, competitive products, news, the development of the system or project itself, and by factors such as weather and climate. Over time, it changes what the customer is prepared to pay in terms of money, time and risks ('affordability'). To keep track, the Value Engineering process challenges values ('how much are you willing to invest for a certain function or performance') through rapid design iterations, by prototyping systems, by measuring and analyzing value upfront (before much design work is done), by investigating alternatives and by checking frequently the outcomes and costs that are linked to functions, system performances and perceived values.

The value concept from the view of systems engineers

In our survey, systems engineers considered the inclusion of the value concept in the development process as an important contribution to Systems Engineering. Foremost, it was mentioned that the value concept enables the definition and comparison of alternatives that would not have been compared otherwise. Other advantages of the value concept that the systems engineers mentioned were:

- Value as a key performance indicator (KPI) can be monitored throughout the project
- It helps to understand the higher purpose of the real needs and concerns of customers, and to define the requirements that a system should meet to fulfil those needs and concerns
- In the concept stage, it can support to define and structure the needs and requirements for the project (needs specification)
- It helps balancing the functions and requirements to the system, by focusing on the most needed functions/capabilities
- It offers an extra viewpoint to discuss and compare alternative system characteristics and design solutions.

A disadvantage that was mentioned was that it can be difficult to relate value to costs in a consistent way.

THE VALUE ENGINEERING WORKSHOP

The second concept of Value Engineering we explore in this article is the Value Engineering Workshop. As mentioned in the previous sections, value is subjective and related to customer and other stakeholders' perceptions and views. It needs to be deliberately and explicitly explored and defined carefully. This is done in a multidisciplinary stakeholder workshop, including a Value Engineering team that consists of designers, cost engineers and major stakeholders (system users, interface users, other departments, and maintenance engineers). Multidisciplinary teams help explore domains that are unknown for some or most of the team members, and help explore impacts on domains that are hard to access. The workshop follows a structured and systematic seven-step design process, which is called the 'job plan' and is based on American ASTM (2018) and the European EN standard (European Standard EN 12973:2000). By conducting the workshop, the concept of value is explored and defined in such a way that it generates the support of the entire team.

The steps of the job plan are:

1. inform each other to gain the same level of knowledge of the system design, and develop a value profile;
2. analysis of the system functions in a so called FAST-diagram (Function Analysis System Technique), specification of the performance of functions (FPS), and other relevant analyses;
3. a creative phase in which the Value Engineering team generates alternative ideas that improve systems value, using earlier analyses, and by applying several creative techniques;
4. evaluation and selection of the generated ideas;
5. further development of the ideas (multiple iterations are possible), making trade-offs including cost and performances;
6. draw conclusions on potential improvements of the system, define the next actions for implementation, and formulate advice for higher-level management and decision-makers, including issues where the Value Engineering team 'agrees to disagree';
7. presentation to the management/decision makers.

Decision making happens after the Value Engineering study and most often not by the participants. This gives the participants peace of mind to go beyond standards, current practices, and usual habits and methods. This, in turn, enables innovations, cooperation between team members, lowering tension among people, giving room for better listening (and analyzing), and preventing 'jumping to conclusions.' It also enables better decision-making because the advice given by the team is transparent, traceable, and often complete (unless the wrong people were in the Value Engineering team). The advice should show where, how and when functions and performances can improve for a good price: adding value to an existing design.

Workshops require time boxing. This means putting clearly defined time limits on the workshop team. In Value Engineering workshops, people are in the same room at the same time, sharing the same information, and analyses, and inspire each other with creative solutions and shared judgments. That contrasts with the often-used design methods in which regular meetings, email sequences and filled SharePoint must facilitate the communication on the system designs, but which often distracts from value creation. In our opinion, Value Engineering workshops, or similar types of workshops that explore value in a multidisciplinary and condensed way, should be embedded in regular design processes to take advantage of the long-term methods (often systems engineering processes) and the intermittent validation and optimization from the value perspective.

The opinion of the systems engineers on the Value Engineering workshop

According to the survey, systems engineers praise in the VE workshops mostly the enhanced stakeholder engagement and the opportunities to explain and validate the design. Also, the dedicated attention for creativity is mentioned as superior to techniques where individuals cannot take advantage of creative group techniques. Moreover, the Value Engineering based creativity techniques improve the generation of alternatives, giving more inspiration than 'just specs.'

In addition, the systems engineers appreciated the improved decision making based on 'added value' for the stakeholders and value as a measurable requirement. The engineers mentioned that this prevents decision-making solely based on budget ('lowest price'), and can create opportu-

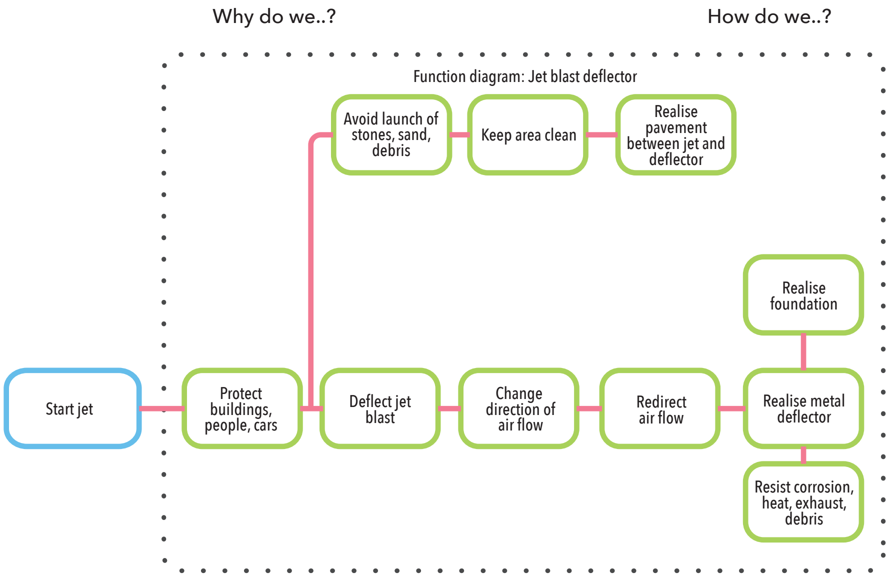

Figure 2. FAST diagram example

nities for funding (since functions and its costs can be attributed to various stakeholders). Expected disadvantages that were mentioned are that too many parties may become involved in decision making, and that personal interests and ideas might prevail above business goals.

THE FAST DIAGRAM

The final concept of Value Engineering that we discuss in this article, is the use of the FAST diagram. The FAST diagram is scheme with functions that are connected to one another through a specific HOW-WHY logic. The FAST diagram example shown in Figure 2 visualizes HOW-WHY relations between functions.

Questioning the reasoning was practiced already by the philosopher Socrates (400 BC) and the FAST diagram is doing the same. It creates the opportunity to ask for all reasons of existence of system functions. It validates the existence of the functions both to client and the designer. What questions would you ask to the designers of the deflector (see the function diagram)? Does it inspire for other solutions because you know more potential solutions for a function? What questions would you have for the client?

Not only are there more solutions possible for a function (which is common knowledge for systems engineers), but there are also more functions possible that can fulfill a higher order function. This function model stimulates new reasoning and alternative function models and, hence, can lead to improved systems.

In addition, the FAST diagram allows for allocating costs to functions, as the objects that fulfill functions cost money. This makes it possible to show the price of a specific functional chain of reasoning. So, the question 'does the function make sense from an economic point of view' becomes part of the investigation into the system. That often leads to alternative designs.

Finally, the FAST is an additional method to model the functionality of the system and can be used complementary to other types of function analysis, each of which is has specific advantages in certain contexts, such as:

- Defining the different states of a system by using the state/mode analysis
- Defining the functional interaction between the system and its environment by using sequence diagrams
- Defining the sequence of the functions by using functional flow diagrams
- Analyzing the different failure modes and depending on the effect add mitigation functions with the failure mode, (criticality) & effect analysis (FMECA)
- Reasons for existence of a function, visualized with FAST diagrams.

Survey results related to the FAST diagram

With regard to the FAST diagram, the systems engineers indicated that the FAST method is a relevant contribution to the Systems Engineering functional analysis. Mainly because the FAST focuses on the 'why' question. This reveals real needs and challenges and clarifies the real value of a system. It reveals the reasons why certain requirements are wanted by the client and enriches function analyses by providing more context and understanding about complex reasoning. Consequently, it helps the design team develop better solutions to problems when those reasons and context are clear.

Moreover, some respondents advised to apply the FAST thinking already during the needs analysis in the concept stage, in order to define the functionality required by the stakeholders. It was also mentioned that the FAST could be one of the methods to validate the system and to determine the degree of design freedom.

WHEN TO USE VALUE ENGINEERING

A final question we want to address is: 'When is the best time to use Value Engineering?' Within the Systems Engineering process, a Value Engineering process is often used for three reasons: Value Planning, Design Validation and Trouble Shooting. When Value Engineering is applied for Value Planning, it means that at the start of the system development process, a Value Engineering workshop offers a playground where functional analysis, requirements analysis, requirements validation and the value definition of the system are coupled together and offer a quick acceleration and focus in the system development process.

When Value Engineering is applied for Design Validation, it is not only used to validate the system, but also to put the system to a test in terms of customer value and ever-changing customer preferences, needs and concerns.

Finally, Value Engineering can also be used for troubleshooting. Often to solve problems such as a lack of acceptance of the system architecture and design, difficulty to control the overall costs of the system, conflicting system requirements, difficulty to align with existing design standards and possibly uncertainty due to changing customer preferences.

CONCLUSION

In this article we explored opportunities to incorporate concepts from the Value Engineering perspective in systems engineering processes, tools and activities. We described three concepts and tested them with a survey with systems engineering practitioners who, in general, confirm our findings. We avoided writing about 'systems engineers' and 'value engineers' but focus instead on the concepts that add value to engineered systems, valued highly by its users. Systems engineering and value engineering are not mutually exclusive, but offer outstanding concepts to improve designers' goals. We hope to inspire engineering practitioners to weigh, rethink and adapt methods, and invite the systems engineering and value engineering communities to further explore and experiment together.

SUPPORTIVE MATERIAL

This article is constrained to six pages and therefore, more tools and their expla-

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