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► To cite this version:

Alexis Lalevée, Nadège Troussier, Eric Blanco, Mahmoud Chakroun. Using Value Analysis and System Engineering for complex projects. 17ème colloque national S-mart AIP-PRIMECA, Université Polytechnique Hauts-de-France [UPHF], Mar 2021, LAVAL VIRTUAL WORLD, France. hal-03296144v1

HAL Id: hal-03296144

<https://hal.science/hal-03296144v1>

Submitted on 22 Jul 2021 (v1), last revised 22 Jul 2021 (v2)

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Using Value Analysis and System Engineering for complex projects

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Abstract— *Value Analysis (VA) is a collaborative method that could be used to make decision-making in complex projects. System Engineering (SE) is a design method used in complex projects. In complex projects, stakeholders are multiple and carry specific technical, social and environmental expectations that define the value of the project. The aim of this paper is to demonstrate that VA and SE are two complementary approaches to collect and analyze Stakeholders’ expectations in a complex project. The paper presents a literature review on VA and SE that show the complementarity of the methods to involve Stakeholders in projects. From this analysis, a case study is proposed to illustrate the complementarities of the method. The paper concludes that the two methods VA and SE can be combined to analyze and track multiple dimensions of value (economic, social and environmental) within a complex project.*

Keywords— *Complex Project; Stakeholder; System Engineering; Value Analysis*

I. INTRODUCTION

Value Analysis (VA) is a well-known method able to be adapted in many contexts [1]. Due to the adaptability and a stakeholders-centered approach, VA is used to support decision-making especially in the early phases of the project when requirements and principle of solutions are defined.

For complex systems, System Engineering (SE) is today the mainstream methodology used in industry. According to [2], SE “technical processes are life cycle processes”. The phase of architecting is the result of aggregation of the “stakeholder requirements definition” and the “requirements analysis”. Thus, this first phase of architecting represents a conceptual level of engineering in which Stakeholders are taken into account defining the value of the project for each of them. The interrelations of stakeholders are complex and the understanding and clarification of value is difficult. This step of architecting is then a stakeholders-centered one. Unfortunately, group practitioners’ often estimate that this step is most of the time reduced at some few exchanges. However, in complex systems projects, the value is multiple including economic, social and environmental expectations from stakeholders. The questionnaire method seems to be commonly used as revealed by the Stakeholder Value Network approach used by [3]. The consulting branch of Assystem, Euro Contrôle Projet (ECP), is specialized in project consulting and part of their work consists in supporting companies in the management of technical installations and infrastructure projects. In this context, project delivery is one of major preoccupations. Thus, two branches have to contribute to project success: the management one and the

design one. In the early phase of a technical project, it seems that the two aspects have to be mixed to make a decision in order to achieve a complex project, with a dynamic point of view as shown by [4]. As highlighted by [5], it is recognized that the quality of the execution of the early project phases is critical to project performance. Yet, early project phases received limited attention in past research. Uncertainty and the influence of project stakeholders are presented as two key success factors of projects [5]. Practitioners observe that the value is often reduced to economic value and projects may lose environmental and social value that are stakeholder expectations.

With a practical approach, it seems that VA and SE could be combined not only to design a complex system but also to ensure the project delivery, with a stakeholder-centered approach. As highlighted by [6], "Systems Engineering and Value Engineering [...] offer outstanding concepts to improve designers' goals". In this research work, we have made the hypothesis that VA should complement the phase of architecting to ensure the success of the project with a Stakeholder-based approach.

The aim of this paper is to understand how it is possible to combine VA and SE in order to facilitate collaboration between management and technical actors to achieve Stakeholders' expectations linked to sustainable issues, as social and ecological ones. The next section will present a literature review to compare VA and SE through their capacity to perform a deep stakeholder analysis. It enables the identification of the complementarities of the two methodologies. The third section is driving the same analysis based on the company use of VA and SE on a representative case study. Based on these two sections, authors will conclude that VA and SE are able to be used in the same project and discuss the advantages and limits of this proposal.

II. LITERATURE REVIEW

A. Value Analysis

Value Analysis is supported by different standards as [7], [8], used in Europe to frame its applications. Originally, VA was defined as a cost-cutting tool, allowing redesigning products more competitively [1]. That limited vision reduced the extension of applications of the concept into other levels of management. Many different works and applications had developed the concept and the methods. "We can find a tremendous number of different learning exercises and theoretical evolution from that work, but that has not yet answered many aspirations regarding the initial concept of value and value analysis. VA has evolved or is yet evolving" [1]. It shows that the method is able to be adapted to many situations. The concept of value was customer centric and became stakeholder based in the last standards evolution. [9] had shown that VA is a method able to support Sustainability value integration within early phases of a complex project.

Concerning Stakeholders approach, we can say that there exists multiple possible views due to multiple applications of the methodology. Indeed, as underlined by [10], VA uses the workshop system to produce brainstorming synergies. This

collaborative work is used to support decision-making in project management. Thus, Stakeholders are involved into and throughout the project and its success is optimized. The method is based on a Functional Approach (FA) that treats functions that respond to stakeholders' requirements and systems finalities. What the system is supposed to do. However, this method is completed with another approach that treats positive or negative externalities of the system: non-functional needs. They are treated and used to compare some solutions proposed within different scenarios. These other needs are often subjective and difficult to estimate. They are mainly based on social or environmental issues as the quality of life at work or corporate branding. All along the method, a collaborative work in group is used to permit collective intelligence and a VA leader is designated to assure good practices. Often consultancy companies play that role. In VA, Stakeholders are often managed within workshops to elicit the multiple dimensions of value of the project. The next section will discuss how SE approached the stakeholder involvement.

B. System Engineering

With a general viewpoint, "SE is a transdisciplinary approach and means to enable the realization of successful systems. Successful systems must satisfy the needs of their customers, users and other stakeholders", [2].

As evoked earlier, a phase of "architecting" is used before the main phase of design of a system.

According to the general guide [2], SE approach is guided by a stakeholder-centered approach. However, with a more detailed study, we can find that:

- Stakeholders are questioned at the beginning of the project, during the "architecting phase", according [2] Their requirements are relieved with questionnaires [11]. This research is based on a specific phase of SE study dedicated to stakeholders' requirements elicitation.
- Requirements correspond to a very technical view of Stakeholders needs: as illustrated by [2], "a systems engineer helps ensure the elements of the system fit together to accomplish the objectives of the whole, and ultimately satisfy the needs of the customers and other stakeholders who will acquire and use the system".
- A non-specific view of the context of the project is proposed: according to [11], some artefacts are researched and used.

Observations conducted us to determine some limitations of the SE view of stakeholders-centered system as the fact that involvement of Stakeholders seem to be limited by the method used. We will discuss it more precisely in the discussions section.

C. Main findings of the methods review

Our analysis is based on two dimensions 1) to list the different phases of considering stakeholders in each of the methodologies and 2) to characterize them in relation to the

way in which they are involved. The next step is to compare their characteristics, presented in Table 1.

| | Methods | |
|--|---|---|
| | Value Analysis | System Engineering |
| Objectives | To optimize a project | To design complex project |
| Stakeholders' involvement | As soon as the definition of the objectives of the project | "As early as possible" |
| Stakeholders' interrogation | Collective works and sometimes questionnaires | Questionnaires and interviews |
| Uncertainty treatment (of the project) | Operational KPIs are used to reduce uncertainty | based on risk analysis |
| Stakeholder influences | Is relative to workshop composition. No tracking indicator identified | There is no direct influence between the Stakeholders. No tracking indicator identified |
| Decision-making | Based on collective works, by project decision-makers | Based on formalization of Stakeholders' needs, by system engineers |
| Main references | [1], [7], [10] | [2], [12], [13] |

Table 1: Comparison of VA and SE approaches

Both methods highlight the importance to involve Stakeholders in the early phase of the project. Major difference comes in the way it is supported. VA imposes collective work to build a consensus, while SE is mainly based on formalization and collection of individual interrogations. VA focuses on common agreement while SE targets exhaustivity with decisions made to respond to Stakeholders' expectations according to their importance in the project.

In conclusion, the analysis emphasises that Stakeholders' management with a collective approach, it is to say VA approach seems 1) to permit to reduce the uncertainty of the project (linked to its complexity) and 2) to try to take into account some influences between project Stakeholders contrary to the SE approach, mainly based on individual relationship and choices.

In the following section, the analysis proposed is illustrated with a company practice using the illustration of the use of VA and SE on a representative case study of complex system design.

III. CASE STUDY

A. Presentation of the case study

The case presented thereafter was used to demonstrate that VA is a method able to introduce sustainability issues into project management [9]. The case used concerns the design of a transportation facility and policy between two cities A and B far from about twenty kilometres each other. The project's aim is to find some solutions to link up A to B globally more efficiently. In fact, existing small roads between A and B are overload and a highway exists near to B from North to South without any exit to lay out B. Furthermore, some residential subdivisions were built on the outskirts of both cities; a river is situated at few hundred meters of A and B South's limits, and there is a mountain to the North. These topological constraints do not let us think about an "easy" solution. A consulting

company is solicited by the Government to determine what is the project (management and Stakeholders) which would design the best solution.

Value of the project is complex since it has multiple dimensions: social, political, economic and environmental. Many stakeholders are concerned by the project. Multiple solutions exist with complex links between Stakeholders and with coupled dimensions that make the complexity of it.

B. Implementation of the interface

1) A VA approach

- Identification of Stakeholders:** to treat this case, the context is important: who are the different Stakeholders? This first step of work, identification, is made with the Government, which already knows some of them through contact established and different early studies as topographical or socioeconomic ones. However, this is an iterative process to be comprehensive and to be able to evolve. Thus, Government that funds the project is also the decision-maker. Citizens of the zone concerned are implied as all companies (and workers) that will work on the project. Many Stakeholders could be identified: in this case study, around fifteen exist. Numerous and varieties of Stakeholders are a key element: it requires analysing the Value of them concerning the project in terms perception of "cost" and "benefits". It is made through a Function Approach described below.
- Identification of the needs and functions associated:** after having identified all Stakeholders, it is crucial to know what they really need, and to characterise it. Each Stakeholder needs are expressed through a Function Analysis approach. Linking A and B corresponds e.g. to transport people and facilitate exchanges. It corresponds respectively to cities expectations and Government's one. For each step of the life cycle, functions are characterized and ranked by "order of importance" for Stakeholders. In this case, collective work is important because it permits Stakeholders involvement. The most important function is "to transport people" that is noted with 65% of the importance of the project while "to facilitate exchanges" have 35% of Stakeholders preferences. Thus, the Government wants to improve exchanges between two cities to enable the Economic Value creation, within a given budget. Thus, the aim of the project is to perform functions within an optimized cost. Citizen's life is at stake also with traffic jams reduction, which is reported to Social Value. Objectives of reducing pollution at

the same time with public transports, refers to Environmental Value. Moreover, inhabitants of both cities and peripheral ones, neighbouring ecosystems like river and mountain, have to be taken into account also. Thus, a systematic life cycle step's approach has to be performed to elicit all needs of Stakeholders at each step of the project lifecycle. In this case, several needs are identified leading to about ten functions. These functions are used to determine real needs that complex projects have to respond to. Finally, solutions and scenarios that combine multiple solutions are compared to Stakeholders needs and are evaluated.

2) A SE approach

SE is represented through a generic life cycle model (fig1 SEBoK Original). In this representation, we can see that there exist different steps, with one major, the "architecting phase" dedicated to definition of the concept and definition of the system. "The model is defined as a set of stages, within which technical and management activities are performed. The stages are terminated by decision gates where the key stakeholders decide whether to proceed into the next stage, to remain in the current stage, or to terminate or re-scope related projects". according to (INCOSE and IEEE Computer Society, 2016).

These steps are applied according (INCOSE and IEEE Computer Society 2016) on our case study: we will consider that these macro-steps are representative of all SE approaches.

- **The Concept Definition:** Government decides to invest resources in the project of linking A and B cities. The first step is determining a set of stakeholders that have interests in the engineering project: citizens, and different government administrations are concerned. Activities during this phase include the development of the concept of operations and business case; determining the key Stakeholders and their desired capabilities; negotiating the Stakeholder requirements among the key Stakeholders. Questionnaires are used to interrogate Stakeholders. Decision-makers and System Engineers lead this first phase of SE.
- **The System Definition:** this step begins when the Government, the key Stakeholder of this project, decides that the business needs and Stakeholder requirements are "well defined". It is an iterative step in which solution options are progressively detailed. It is the basis of system realization. Activities during this phase include the development of the system architectures (physical, numerical, etc.); the definition and agreement of the levels of system requirements; and the definition of the expected performances, as the number of trains per hour. The transition into the system realization

stage can lead to either single-pass or multiple-pass development, led by SE engineers.

- **The System Realization:** one more time, this step begins when decision-makers, it is to say Government, decides that the project architecture and feasibility evidence are sufficiently low-risk to justify committing the resources necessary to develop and sustain the first phases of project realization.
- **The System Production, Support, and Utilization (PSU):** one more time, this step begins when decision-makers, it is to say Government, decides that the project is sufficiently low-risk level that justifies committing the resources necessary to produce, field, support, and utilize the system over its expected lifetime.
- **The System Retirement:** this step is often executed incrementally as system versions or elements become obsolete or are no longer economical to support and therefore undergo disposal or recycling of their content. Increasingly affordable considerations make system re-purposing an attractive alternative: maintenance and internal processes are deployed to assure the quality of services and expected performances regarding clients, it is to say A and B's citizens that have to travel between these cities.

To conclude, we have seen that each step of SE consists of iterations and adjustments, it is to say that SE takes into account an internal form of dynamism. However, this dynamism is not directly linked to the Stakeholders: they are interrogated through questionnaires only one time, at the beginning of the project and system engineers are in charge of creating and implementing the project, based on one vision at a precise moment of Stakeholders of the project. We can also notice that decision-makers have power: they are informed and involved in all steps of the project while other Stakeholders are not.

C. Preliminary conclusions about VA and SE

In this section, we will present what are complementarities and major differences between the two methods, Value Analysis and System Engineering.

1) A VA/SE comparison

The Table 2 offers the same comparison as that made with the literature review, but this time adopting the point of view of the case study:

| | Methods | |
|------------|--|---------------------------|
| | Value Analysis | System Engineering |
| Objectives | To optimize a project with Stakeholders' | To design complex project |

| | Methods | |
|--|--|--|
| | Value Analysis | System Engineering |
| | involvement | |
| Stakeholders' involvement | As soon as the definition of the objectives of the project | As soon as a technical architecture is defined |
| Stakeholders' interrogation | Collective works | Individual questionnaires |
| Uncertainty treatment (of the project) | To compare solutions, Stakeholders are contributors: they define requirements, risks and opportunities with their own experiences, in the workshop | Solutions are over-provisioned to take into account risks, based on system engineer experience |
| Stakeholder influences | VA leader try to limit the phenomenon (with group management) | External influences exist on system engineer |
| Decision-making | Based on the collective works by decision-makers | Based on individual Stakeholder needs, by system engineer |
| Main references | [1] and internal company sources | [2] and internal company sources |

Table 2: Comparison of VA and SE approaches

We can remark that, with a practical approach, the major difference is the fact that VA uses collective work, while SE uses individual interrogations with decisions made to respond to Stakeholders' expectations. On one hand, the collective approach permits to have a systemic view of the project and permits to treat some uncertainties, to have a constructed support to decision-making; it is to say a methodology used to permit Stakeholders' involvement to assure project success. On the other hand, we have SE that permits to design complex systems within a complex technical framework while decisions are mainly based on questionnaires and reduce exchanges between designer and Stakeholders. Formalization of stakeholder expectations is a valuable input.

2) Conclusions

In this comparison, VA and SE approaches of Stakeholders appear to be complementary. Indeed, if VA approaches lead practitioners to have Stakeholders involvement on the project and the possibility to make decisions, SE advantages seem to be linked to the fluidity to make decisions (only one Stakeholder in our case study) and many iterations are made all along the project lifecycle. It has to be noted that SE treats the ideation concept to dismantling one, while VA is mainly used in early phases of the project with a macro-vision of the project. As described by [6], system engineering and value engineering communities should "explore and experiment together" to "improve designers' goals" to improve Stakeholders' involvement on projects through a systemic approach of their requirements.

IV. DISCUSSIONS

Firstly, we showed that VA is a method able to be adapted in all contexts and is well adapted to make decisions based on Stakeholders, in the context of complex projects. Moreover, Stakeholders are involved all along the project with a collective approach in VA. Thus, project success is facilitated

with decisions made as soon as conceptual phases of the project. Secondly, it has been highlighted that SE is a method able to design complex projects. Stakeholders' needs are treated, through questionnaires and interviews, by system engineers that are in charge to design these systems.

Thus, in this section, we will discuss in one hand differences between theoretical approaches and practical ones for each method and in other hand the interest to implement SE approaches with AV ones, to involve Stakeholders on projects of system design.

A. The architecting approach vs VA approach

In this part, we will compare the two approaches of Stakeholders. Indeed, it has been seen that within a theoretical framework, Stakeholders seem to be more involved with a VA approach than a SE one. VA uses group works while SE uses mainly individual approaches, based on questionnaires and interviews. Exchanges permit not only collective intelligence through exchanges made during phases of the project but also an involvement of Stakeholders with a VA approach. SE advantages are linked to decision-making: it is quicker due to the fact that system engineers make decisions based on Stakeholders requirement and that they make trade-offs to obtain coherent systems.

With a more applicative approach, it has been seen that Stakeholders take an important part of VA approach: they are interrogated through groups of work all along the project. With ECP's experience, we can add that they are crucial elements of a project success. This element is comforted by [5]. Thus, authors can make the hypothesis that another system of Stakeholders' involvement on a SE framework should improve success of projects.

Thus, we could think that SE and VA approaches of Stakeholders should be implemented to a better involvement of Stakeholders all along a complex project. It is what is discussed in the next paragraph.

B. The interest of an integrated approach of Stakeholders

In this section, we will highlight the interest of having a systemic and integrated approach of Stakeholders. Indeed, as evocated earlier, they are key elements of the success of a project. As highlighted by [2]: "Understanding the needs of all stakeholders inside and outside the company" take part of major activities of a SE approach. We have seen above that VA and SE approaches are complementary to involve Stakeholders in a complex project but we have to show what are key elements to support a "mixed" method. In fact, if they seem to be complementary, both methods have particularities as the method to interrogate Stakeholders. What has to be determined in future works is the manner to use together the two methods to obtain a global method able to take into account and integrate Stakeholders all along a complex project.

VA seems to be a method capable of integrating Stakeholders during early phases of the project and continuing interrogating them all along the project. Moreover, the approach permits a Stakeholders involvement and decision-making that is not only based on technical aspects. It is why VA is

complementary to SE that is based on Stakeholders needs and treated mainly by system engineers with a technical approach. This aspect of the complementarity is reinforced by [6]: in fact, their works show that SE have to optimise Stakeholders' perceived value of a system and show that VA could be a tool of SE. However, some limits are determined in the manner to implement a mixed method: we will discuss this aspect hereafter.

C. VA approach to complement SE: preliminary conclusions

We have demonstrated all along this article that Stakeholder approaches of VA are more global than SE ones to involve them into a project. Thus, authors make the hypothesis that VA should be a complement to the architecting phase of SE to fill the gap of Stakeholders involvement into projects, which lead to uncertainty and project failures sometimes. As underlined by [6] in his works about opportunities of using VA in SE, VA "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". This theoretical hypothesis has some limits as to how to link these two methods with a real application and what should be the language to communicate between the two design phases. These questions raised questions seem to be not treated in the literature review nor with the industrial approach.

V. CONCLUSIONS AND FUTURE WORKS

We have seen that VA is a flexible method able to integrate sustainable issues expressed by Stakeholders. These types of requirements are able to complete the FA that helps practitioners to respond to the technical need. This "technical" need is also treated by SE, with system engineers dedicated. Moreover, with a VA, it is possible to take into account Stakeholders as soon as the early phase of a complex project and keep them involved during the project. Contrary to SE that treats Stakeholders with questionnaires in the beginning of a design project, VA treats them with a collaborative work as soon as early steps of the project: from the conceptual phase. Despite apparent changes, with a theoretical approach, both methods seem at aiming to improve global design of complex projects.

Thus, the interest of VA before SE is a better integration of Stakeholders and what they globally want, not expressed by functionalities, as sustainable dimensions that are non-functional requirements, in early phase of the project that is to say in a phase in which decisions are important and few investments. The work of [6] comes to show, with an SE approach, that our work has not only an industrial interest but also a theoretical one.

Limits of this research are that it is a very theoretical approach of interfaces possible between both methods. Future research works have to be done to validate presented hypotheses and to know how it is possible to apply together the two methods: communication and capacity to integrate each other's indicators have to be worked and validated. To integrate VA

in a SE framework could be a support to improve socio-technical systems design as described by [14].

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