FUNCTIONAL ANALYSIS CASE STUDY RESEARCH USING PATTERN-MATCHING

BACHELOR THESIS REPORT

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Preface

Systems engineering is an increasingly important topic in the development of organizational management engineering practices. Many organizations are trying to improve their organizational setup and practices systematically, to increase productivity and lower the costs of the project's design phase. The research will focus on the production of functions as a systematic process to enhance the functional analysis application in an engineering firm, particularly the FAST diagram method. Ensuring the addition of an epistemic value to the development and research around the functional analysis with its components and a strive to the normative judgment of the findings.

In truth, I could not achieve this current level of success without the strong help of the supervisor dr. Marc van Den Berg with every step of the projects throughout multiple feedback sessions, therefore, I would like to thank him for his support.

Bari Fares

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1. Summary

More engineering firms are transforming their work to organizational set-ups, applying Systems Engineering methodology in their processes to design and deliver their projects, therefore, a good knowledge of the processes and methods that are used to apply the SE methodology, by a thorough analysis. The functional analysis is an important design step in the SE process, that causes some delay and confusion issues to the engineers working on the projects. Delays that cause an increase in the time and cost of the functional analysis process, furthermore, cause a disconnect between the SE model steps (requirements to functions, then objects). This report will take the functional analysis as a case study and focus on the FAST diagram method as a recommended analysis tool that requires a team session to produce functions. The analysis of the case study will use a pattern-matching technique to connect the theoretical (literature) and empirical data (interviews) of an engineering firm, then compare both to understand the situation and find solutions to delay problems.

The case study research will focus on answering 3 questions regarding each type of pattern mentioned and comparison through collecting data and objectively analyzing it. Patterns related to the functional production process, such as Free solution wording of functions, negative wording, hierarchical grouping and decomposing of functions, ...etc. Other important aspects in the organization of the functional analysis team sessions are also analyzed in the case study research, such as enthusiasm, knowledge of the process.

2. Introduction

The development of construction projects is a complex process that is hard to manage, involving high stakes, high risks options with many requirements and interests. To combine those aspects into a project, effective collaboration is needed in the beginning phase of a project design. Many engineering consultancies/companies are looking to transform their work from product-based processes where each project contain new processes different from the previous one with the aim of delivering the product, to a process-based work where all the projects go through pre-defined methods to structure the development process and manage the project assets, (Reuvers 2019). A pre-defined process that can be followed, analyzed, and verified rather than undefined processes that usually depend on the knowledge/expertise of the worker, with no form of organizational set-up. The growth of the construction industry came with more demands, to research increasingly important topics such as the environmental/social impacts of the projects, studying the end of the projects lifecycle, and including it in the design process. New innovative methods have been adapted to include these demands and give the project teams a more structured way to design and deliver projects, such as systems engineering methodology.

For any consultancy/engineering firm that is implementing a construction version of SE methodology with all its processes as a framework to design their projects. During the design phase, the management team faces difficulties and delays regarding the formulation and completion of functions during the functional analysis step (FAST diagram). A solution to the firm's need is to research this problem, to complete the functional analysis that can be derived from the comparison of both the theoretical framework (theories related to functional analysis and SE) and a practical one (organizational and individual practices).

A case study is chosen to research this problem because the case does not follow a pre-defined procedure, it can be planned to depend on the situation and the kind of results expected to be achieved (descriptive, exploratory, or comparative). The interest of this case study report is to research the function production process of the SE model, FAST diagram method in particular; This case study will be analysed using the pattern-matching technique which is an explanatory method that is heavily used to analyse the organizational operations, (Yin 2018). Pattern-matching was chosen to analyse this case study because of the nature of the technique and the results needed to be achieved. It involves the specification of a theoretical pattern, the acquisition of an observed pattern, and an attempt to match these two, providing a stronger basis for valid inference, (Borza 2011). The technique compares the theoretical patterns by reviewing the literature and the documents related to the subject with empirical patterns that contain actual data observed in real-life practices.

This report will first introduce the literature review of the research and its use of it to give an understanding of the theoretical framework/background knowledge of the case study. It also includes the definition of a function and gives examples of functional analysis methods. The next chapter will contain the case study research, including the research objectives, method, questions, protocols, and explanations about the pattern-matching method. In the same chapter, theoretical patterns will be defined (including the FAST diagram method and a display of patterns collected) and empirical patterns (interviews, observations) will be explored. Finally, the comparison between both types of patterns. In the last chapter, the results of the pattern-matching will be presented with the conclusion/recommendations on how to solve the functional analysis problem.

3. Literature review

Systems engineering definition and use:

Systems engineering was first developed by the US department of defense to control, design, and deliver the product of multiple subsystems that the department needs to organize, figure (1), (Defense Systems Management 2001). It is a multi-disciplinary engineering management methodology that helps to transform the company processes and structure to a more organizational form, to define, design, and develop projects in a structured organizational process. It also evolves and verifies an integrated life-cycle balanced set of system solutions that satisfy customer needs (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008).

The complex nature of globalization of industries has increased competition between the engineering companies, forcing them to decrease the cost and development time of projects, thus, more ambiguity in defining the requirements and the lack of proper planning are the major factors that drive the need for a system engineering interference. The use of systems engineering will help the organization to define and fully describe the problems the organizations have regarding steps that should be taken to complete a project, connecting multiple expertise, therefore, the systems engineer adds value only by measuring and reducing risk, (Kamrani, Azimi et al. 2011). Using system engineering methodology will allow employees to follow each process, ensure accountability and reduce the time needed for each process, (Library 2015). Popularized in the Netherlands by the Rijkswaterstaat and Rrorail (PRoRail 2015) as a new paradigm shift to solve project management issues. SE is an interdisciplinary method that includes all expertise to achieve project goals, for all project phases (Initiative phase, Preparation phase, design phase until the demolition phase), (Wiley and Incose 2015). The next figure (1) gives a look into the SE model based on the integration of the different SE stages to design a project. The application of these processes can lead to several benefits for the engineering companies, such as: deciding on well-described functions that cover all the needs/interests, reducing the number of redesigns required to reach the final one, thus, saving time (costly/time consuming). It also achieves better protection of stakeholder's interests, not just client to include all the wishes for the best result, reducing faulty Designs, and ensuring that additional client demand can be added/researched at an early stage and include it in the requirements, (Wiley and Incose 2015).
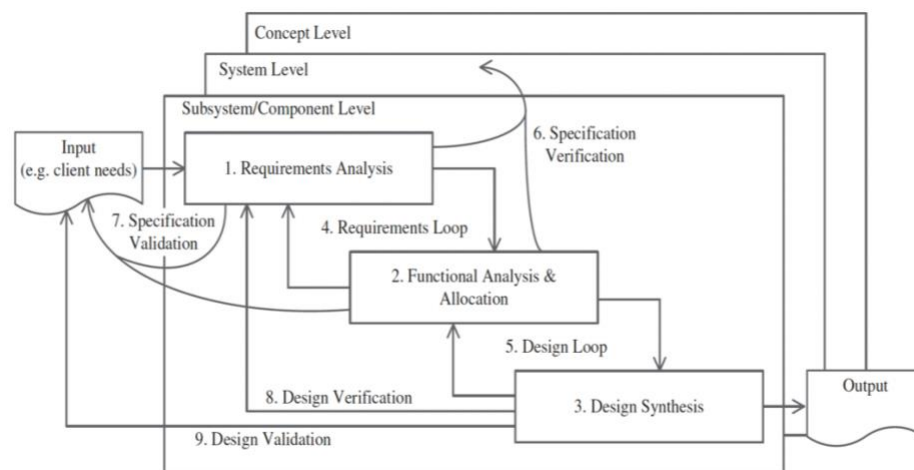
Figure 1: SE process based on the model of the U.S. Department pf defense 200, (de Graaf, Vromen et al. 2017)

The SE model contains multiple stages that should be followed for an optimum solution and to allow the involvement of customers in the design process through the model input, which is an important advantage SE methodology has. It ensures the design development according to the stakeholders' expectations.

The SE stages start with the concept level which produces the system concept description (the concept study); Then it goes to the "system-level" that further gives the system description in performance requirement terms. Lastly, the Subsystem or the Component level, which further identifies a set of subsystem and component product performance descriptions, then a set of detailed descriptions of the products' characteristics, essential for the component production (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008).

Requirements to functions:
At an early stage of the design, after documenting the wishes and interests of the stakeholders (those who affect and get affected by the design decisions), requirement analysis is needed to develop, produce, test, distribute, operate, support, train, and dispose of system products under development that is made by the project design team, (Graaf 2019). As a first step to transform the stakeholders' expectations/demands, to assess its importance and give a better understanding of the intended use of the system. A thorough analysis of the requirements takes place by transforming demands to customer requirements specification (CRS), a stakeholder demands document which gives the problem definition, project objectives, system of interest, and associated requirements for each stockholder, (de Graaf, Vromen et al. 2017). Requirements are then formally determined, written, and analyzed, to determine the essential functions that must be performed, (Kamrani, Azimi et al. 2011).

The project team is then tasked with the functional architecture, meaning, identifying, and structuring the allocated functional and performance requirements. Translating the CRS from a customer-worded document to a design brief (DB) that contains the requirements formulated by the designers. The objective of a design team is to produce a design solution that satisfies initially defined requirements and then communicate it, effectively, and promptly, (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008).

The requirement in this document must also be SMART (specific, measurable, acceptable, realistic, time-bounded), it is an important tool for a later review, to ensure the intended use of the project once it's finished and verified if the system was constructed correctly. Figure (2) looks at the three important SE processes which are "requirement analysis", "Functional analysis and allocation" and "design synthesis". The SE methodology requires these processes to be documented and checked at each step of the design phase to ensure the accountability of decision making and the inclusion of the stakeholders' requirements in the decision-making (Reuvers 2019).
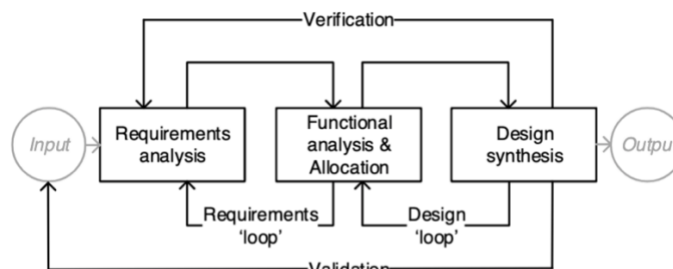

Figure 2: The SE process model at every stage (Graaf 2019)

Requirements should also explain the constraints the project and system have, that will impact the solution design.

The constraints are external such as the public and international laws the team should follow or internal according to the customer interests and needs from the system. Performance and functional requirements on how the system should perform after the realization and the environment that will perform in, that can be tracked through the TPMs (Technical Performance Measures) which are indicators of the system performance tracked during the design process. The system characteristics identification that will determine the requirement and the functions later (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008) while ensuring the customer interests and needs through MOEs (Measures of Effectiveness and Suitability) that includes measures of supportability, maintainability, and ease of use.

Assigning functions effectively and efficiently is a hard task that requires a lot of time and effort, further, it can cause a delay in the project design process. Another factor that can cause difficulties and delays is the creation of functions for a project, especially during a COVID-19 pandemic that causes a change in the communication tools and habits between the employees. During the production of functions -FAST diagram method- multiple sessions are requested to brainstorm ideas between the different experts/engineers from different departments and disciplines, to give their input on the functions that the system should have and perform. An integrated team requires preparation and a good level of theoretical understanding between the members, a knowledge of the framework to produce these functions. This case study will research the delays factor in function production for better application of the FAST diagram method and ultimately the SE methodology in the construction management industry. This plays an important role in the case study problem, facing engineering firms regarding functional analysis completion. Insufficient and erroneous specifications, as well as requirements that

are overlooked, are important issues that continue to affect the cost (extra costs). The cost of a revision increases by a factor of ten for each stage, therefore, early intervention is needed, including both the stakeholders and the design team iterations of the functions list, (ElMaraghy 1998), Figure (2) presents the cost of changes throughout the project phases (ten to one).
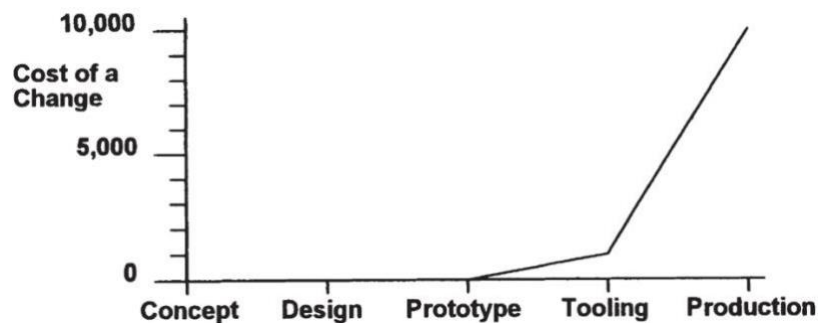
Figure 3:The product development change cost, (ElMaraghy 1998)

Different methods are used to apply the functional analysis and allocation step. The next chapter will explain and compare a couple of methods that can be used to achieve sufficient analysis, with the focus on the FAST diagram method that is used by the engineering firm.

3.1 Functional analysis methods & comparison

This chapter will present a comparison between the different methods and used to highlight the important aspect of each method and the difference between them:

1. Functional Flow Block Diagram:
It is a method to perform the functional analysis by covering all the life cycle of a project or design of a product and converting it into blocks that contain the sequence of all tasks and elements that should be performed. It defines the task sequences and relationships, support requirements are identified to specific system functions, (DUA)

Advantages:
Proper sequencing of activities and design relationships are established, Functions are numbered for more clarity, Functional reference, Flow connection: Lines connecting functions only indicate function flow, Flow direction: Diagrams are laid out so that the flow direction is generally from left to right, Summing gates and/or for better control of the functions and their utilities/ relation to other functions.

Disadvantages:
It does not specify the time needed for the beginning and completion of a function or intermediate activity. No hierarchy of the functions is essential in understanding the sequence of tasks.

Figure 4:Functional flow block diagram, ((Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008))

2. Integration Definition for Function Modelling (IDEF0):

A common modelling method used to define process and data flows, mostly in software-related designs, for the analysis, development, where it can graphically represent and integrate multiple aspects of the design business in one diagram, (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008).
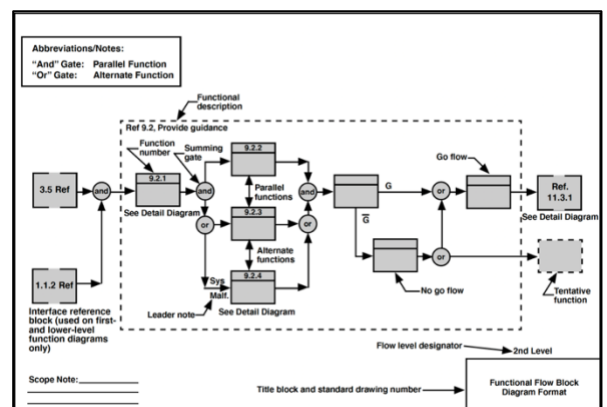
Advantages:

Allows for feedback (going back to previous functions)
, a good description of the process sequence,
Proper sequencing of activities and design relationships are established, Functions are numbered for more clarity, Flow connection: Lines connecting functions only indicate function flow, Flow direction: Diagrams are laid out so that the flow direction is generally from left to right.

Disadvantages:

A basic diagram with low control of the functions does not specify the time needed for the beginning and completion of a function or intermediate activity and no timeline to indicate the operation time or overlapping.
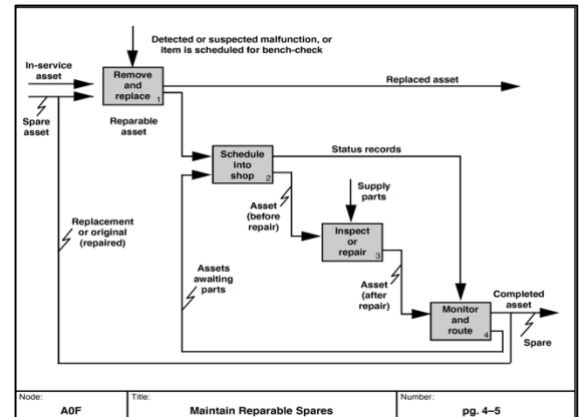
Figure 5: An example of IDEF0 diagram model, (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008)

3. Timeline Analysis Sheets:

It is a functional analysis technique that heavily relies on the duration of each function analysis and adds detail to defining various functions. It defines the time sequence of time-critical functions, (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008).

Advantages:

Concurrency, overlapping, and sequential relationships of functions and tasks, timeline analyses that define the time sequence of time-critical functions, that directly affect system availability. Operating time, and maintenance downtime. Numbering of each function, following sequence.

Disadvantages:

less description of the functions with no feedback for previous functions.
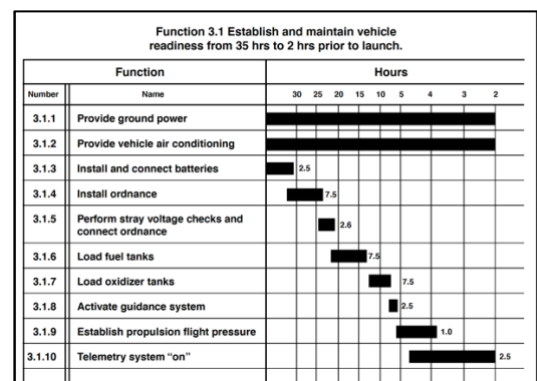
Figure 6: TAS example sheet, (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008)

Functional analysis methods comparison:

Table 1: Multi-criteria functional analysis comparison

	The presence of secondary functions	Hierarchy (levels) of functions	Numbering of the function sequence	Duration and overlap of function	Allows for feedback between functions	More Suitable for integrated teamwork
Functional Flow Block Diagram	●		●		●	●
Integration Definition for Function Modelling		●	●		●	●
Timeline Analysis Sheets	●	●	●	◐		
FAST	●	●	●		●	●

4. Case study research

A systematic approach should be taken to solve the case study problems and give a valid solution that is based on legitimate evaluation techniques. Questions and sub-questions that explain and compare the theoretical knowledge and the empirical evidence gathered from the practices, about the process of creating functions and the difficulties that comes with it. A "research case study" fits the situations where a comparative analysis is done with questions containing "how" (e.g. How to solve an issue?) and why (e.g. Why the issues are happening?), (Yin 2018). The advantages of using case study research instead of other techniques are that the case study only studies contemporary issues (real-world context) that took place around the current time and does not try to search for historical phenomena, (Yin 2018). Secondly, a case study is used when the researcher does not have control over the behavior of events, in this case, the reactions of the employees to the different questions and decisions taken during the design of previous projects. Lastly, case studies always tend to generalize the solution produced to add a theoretical value to the general research by applying it in other situations which creates a level of robustness and validity to the process.

4.1 Case study analysis method (Pattern-matching)

This case study will be analyzed using the pattern-matching technique which is an explanatory method that is heavily used to analyze the organizational operations of work processes (Yin 2018) Pattern-matching was chosen because of the nature of the technique and the results needed to be achieved. it minimally involves the specification of a theoretical pattern, the acquisition of an observed pattern, and the attempt to match these two, providing a stronger basis for a valid inference (Yin 2018). This case study will use the pattern technique to compare the theoretical patterns by reviewing the literature regarding Functional analysis and production in the SE methodology with the empirical pattern observed and recorded during the interviews, (Yin 2018). Pattern matching tries to compare the practice framework with the predicted theories then match them to find their occurrence as qualitative data for each pattern (the likelihood of occurrence), (Trochim 1989). It should be noted that to use this technique in investigating the theories of a pattern, other rival theories should not be plausible or close to the same benchmark.

The criteria to choose an appropriate comparison benchmark for both patterns are based on multiple factors to ensure the correct collection of the right info and then turn it into patterns, factors such as:

❖ Causalities and similarities: Between the literature patterns on the FAST diagram of functions with the practices done by employees to create it.
❖ The likelihood of occurrence: If a pattern of both theoretical and empirical keeps accruing multiple times, e.g. An ambiguity or clarity of knowledge in an area regarding the creation of a FAST diagram for both interview participants.
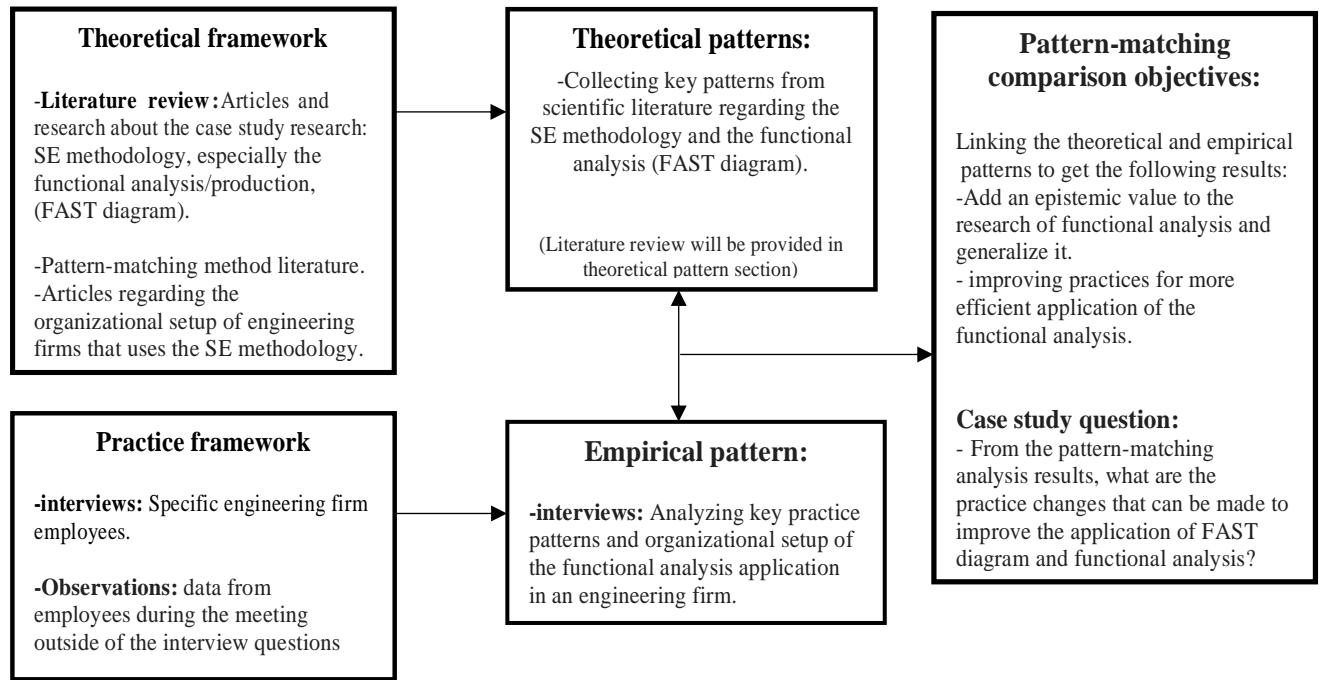❖ Observed occurrence: Problems in the Organizational setup of the engineering firm.

Figure 7: objectives Pattern matching components, (van den Berg, Hartmann et al. 2017)

4.2 Case study Objectives

The case study objectives are divided into three parts for each type of pattern, to maximize the epistemic and practical value of the case study:

❖ **Theoretical pattern objectives:** The aim of exploring the theoretical patterns is to get a good level of theoretical saturation from readings, meaning, until no new insights can be explored of literature regarding the FAST diagram and the functional analysis. figure (3). This will add an epistemic value to the development of theories regarding the functional analysis and allocation of SE methodology, generalizing the case study research (application in other SE studies). Ensuring the theoretical relevance of the literature used in the case study by referencing several studies on SE methodology, comparing other functional analysis methods to the FAST diagram method for a better view of their advantages and disadvantages. Literature on participatory methods (interview) to come up with a case study that closes the gap between theoretical framework (SE methodology literature) and practice framework (practices done by the employees leading and during the functional analysis).

❖ **Empirical pattern objectives:** The case study objectives regarding the empirical patterns are to analyze and give an insight into the mistakes and problems (patterns) the management engineering company face during the functions production of the different projects, by collecting enough evidence using interviews with three employees as a participatory method (the protocols will further elaborate on this process). The formulation of a function (verb + noun), the creation of secondary functions, and the transition from the Design brief to functions are some of the difficulties regarding practices, therefore, this case study tries to find solutions to problems by analyzing practice patterns to instigate new developments or initiate a new organizational policy to reduce the error and consequently the extra costs resulted by the delay.

❖ **Patterns comparison objectives:** The objective is to link a collection of patterns between the theoretical and practical frameworks that are related or lead to each other, thus, a solution possibility arises. Patterns that explain the mistakes made by the employees during the use of the SE methodology, by comparing the different results found from interviewing employees. Linking results and solving the case study question presented in figure (3) while keeping the following criteria/activities in mind:
  ➤ The level of reliance on theoretical patterns during the practical production of functions.
  ➤ Exploring the links between theoretical and practical patterns of each functional analysis.

➤ The level of importance of the patterns and the scores every question will be given.

4.3 Case study questions

❖ **Theoretical**: What are the key steps in creating the functional analysis method (FAST diagram)?
❖ **Empirical**: What are the key practice patterns that play a role in the functional analysis process?
❖ **Comparison (pattern-matching)**: From the pattern-matching analysis results, what are the practice changes that can be made to improve the application of the FAST diagram and functional analysis?

4.4 Case study protocols

For an objective and correct analysis of the case study, a set of rules are needed. Rules to collect the theoretical patterns by choosing the relevant literature that speaks directly to the subject of Systems Engineering, and functional analysis and FAST diagram. Empirical patterns rules for conducting the interviews with engineers working on the subject and collecting/processing the data. A further elaboration on the rules governing the case study is given in this chapter:

Theoretical protocols:
To acquire a deep perspective on the processes (literature saturation), avoiding any missing information that could lead to a false interpretation of patterns and description of the solutions, extensive literature research on the topic of systems engineering is required, particularly the FAST diagram literature. The criteria in choosing the references were taken from the information sharing study (Wijewickrama, Chileshe et al. 2021), criteria to choose the appropriate literature. It is a method to display the included articles and books of a case study. The kinds of literature reviewed for the case study can be found in the next table:

Table 2: Literature sources review

Type	Source	Sources
Included literature	- Scanning Systems engineering handbooks produced by regional companies and institute for better understanding of the SE application.	(Graaf 2019) (PRoRail 2015) (Washington state departement of transportation 2021) (Defense Systems Management 2001, Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008)
	- Scopus, google scholar, science direct, science gate and University of Twente library as a search engine for articles and books on Systems engineering and the FAST diagram, for more credible information.	(de Graaf, Vromen et al. 2017)
	- Articles about value engineering in the construction industry.	(Chamberland 1989, Green 1994, Younker and CrcnetBase 2003, Reuvers 2019,

		Washington state departement of transportation 2021)
	- Articles about researching a case study, patterns-matching method, and writing a report.	(Kamrani, Azimi et al. 2011, Library 2015, Wiley and Incose 2015) (Trochim 1989, van den Berg, Hartmann et al. 2017, Yin 2018, Wijewickrama, Chileshe et al. 2021)
Excluded literature	- Exclude non-engineering articles.	SE methodology in aerospace and electronic fields
	- Exclude conference papers.	

Empirical Protocols:

Interviews were chosen as a technique to collect empirical patterns for the case study; therefore, a set of constraints should be in place to conduct the interviews effectively and efficiently. The interviews were done with 3 engineers that are working with a team on the functional analysis of projects using the FAST diagram as a technique to produce functions. The interviews were conducted online, using the 'Teams' application then they were transcribed (Appendix 2) and translated into patterns to compare it to the theoretical ones.

Privacy of data:
- ❖ Personal info (names, positions in a company) will not be shared with any external parties.
- ❖ The interview recordings will not be shared online and will be stored on hardware that is only accessible by the researcher.
- ❖ The interview answers were the only part that was transcribed and included in the report.

The scoring system:

The patterns evaluation and interviews were analyzed based on a score of three possibilities, to allow for clear answers, avoiding confusion. This method aims to give a clear, distinct, and concise answer to interview questions while maintaining the possibility as neutral by allowing the participants a "partial" as an answer. The possible answers are:

● Indicates the answer "Yes"

◗ Indicates the answer "partially"

○ Empty: Indicates the answer "No"

Pattern matching comparison protocols:

The aim of the comparison between the theoretical and empirical patterns, linking them and solving the case study question presented in figure (4) while keeping the following criteria/activities in mind:

- ❖ The level of reliance on theoretical patterns during the practical production of functions.
- ❖ Exploring the links between theoretical and practical patterns of each functional analysis step.
- ❖ The level of importance of the patterns and the scores every question will be given.

5. Patterns analysis

This chapter will contain an analysis of the theoretical and empirical patterns by first introducing the background knowledge about the FAST diagram and then further elaborating the collection of patterns to decide their contribution to the solutions.

5.1 Theoretical patterns

This chapter will try to solve the theoretical question by further exploring the literature to get a full understanding of functions and patterns mentioned about the components of the functional analysis. Further, the chapter explores the theoretical patterns applied in the application of the FAST diagram method that is related to the empirical patterns and consequently to the solution.

Function production process:
Functions are an important part of the SE methodology since they hold the connection between the system requirements and the objects that will perform them, figure (2). They define what the system must do, which is a task that the system must complete to achieve its aim or goal, ,(Kamrani, Azimi et al. 2011), ,(Kamrani, Azimi et al. 2011). Functions are a very powerful tool for analyzing complex systems and summarizing the descriptions of the tasks that the system must perform and delivered., (Borza 2011)

The functional architecture is a result of the process of creating, analyzing, and allocating functions for a system. A process that will display not just the functions that must be executed, but also the logical ordering of the functions and the corresponding performance requirements. It also offers a functional description of the current system's, (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008). Many concepts had developed to optimize the use of functions in a system or a project such as value engineering and value management that are important to the improvement of the SE processes, to determine the value of the system. Nevertheless, three key items of importance should be balanced in these concepts, (cost, time, and performance).

Value engineering means an analysis of the functions performed by experts, to improve the performance, reliability, quality, safety, and life cycle costs of a system, (Younker and CrcnetBase 2003). It is concerned with the identification of optimum solutions to solve known technical problems, adding practical value. Both value concepts encourage system engineers to use a functional analysis in the design of a system or a project.

Functional Analysis transforms the functional, performance, interface, and other requirements that were selected using requirements analysis into a coherent description of system functions that will be used to guide the Design Synthesis activity (objects). Functional Analysis tries to separate and select as many available functional options as possible, using brainstorming techniques to avoid the missing of any ideas that may offer significant advantages in increasing the value of the system/project. Even throughout the different levels of design (subsystem level, system, system of systems-level), (Viola 2012). The advantages of the functional analysis are to get agreement from the integrated team working on the project, to decide on the basic functions, and to set the scope of the project that will be worked on, therefore, the effectiveness of the team leader and members is an important aspect. Establishing and maintaining the momentum and pace of a team effort is an important function of the team leader in directing the individual phases of a study, (Younker and CrcnetBase 2003)

The main output of the functional tree is, therefore, the identification of the basic functions through the decomposition of the higher-level functions, (Viola 2012). The decomposition of High-level functions into lower-level functions in functional architectures -figure (4)- is based on high-level functions that take place in the operations environment, deciding what should the system perform at the operational level. Lower-level functions are assigned to the system's physical architecture which describes the hardware and software components of the system, (Kamrani, Azimi et al. 2011) and gives an option on how to reach the higher-level function (performance requirements). The functional

analysis allows for a better understanding of what the system must do, in what ways it can do it, and to some extent, the priorities and conflicts associated with lower-level functions.

Functions are a combination of a verb and a noun (e.g., supporting load), therefore, not choosing the right kind of verbs (active, descriptive, and on point) can cause delays and ambiguity for the understanding of a system and its capabilities. A big confusion can occur as the organization and its employees adapt to new processes. Criteria should be set to analyze the right application and allocation of the functions. To allow for the right use of SE tools such as the Functional partitioning process by grouping functions that logically fit with the components likely to be used, to clarify and minimize functional interfaces. The use right use of the requirement loop at different stages to check if the customer demands are correctly included in the design. The design loop is to revisit the functional architecture and to verify the physical design (objects) are connected rightfully to the tasks and their performance requirements presented.
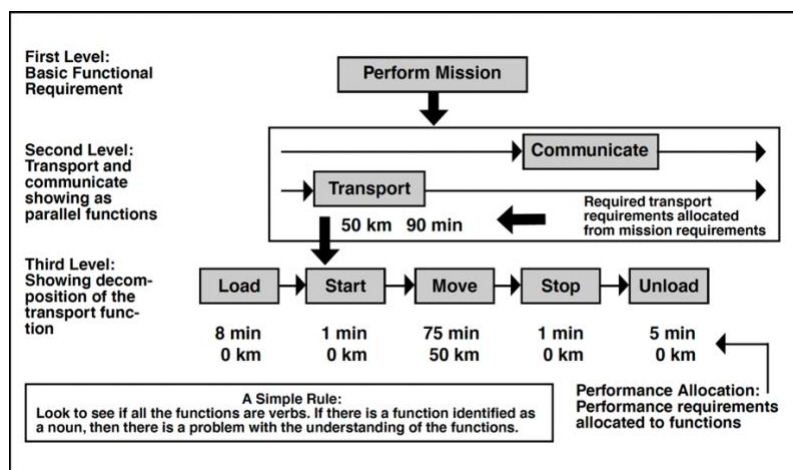
Figure 8: The functional analysis decomposition, (Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008)

Functional Analysis System Technique (FAST)

Fast diagramming is the mainstream method that has been used in Value Management and engineering profession since it was first published at a 1965 SAVE International Conference (Chamberland 1989),(Borza 2011). It is a graphical representation, that organizes the functions needed to be performed, by the product, process, or system under study. Producing functions with a How? /Why? Relationship, while keeping in mind the cost, performance attributes, and user attitudes to select valuable functions, (Washington state departement of transportation 2021).

This method divides the function into different categories for a better understanding of the subject scope and better solution production. The function is a combination of an action verb and a noun, then the function is categorized into, (Borza 2011), figure (8):

❖ Basic Functions: That describes the task, which is the primary reason for the existence of a system or an item. It is the reason why the product or process was designed.
❖ Secondary Functions: These are necessary to cause or allow the Basic Function to occur. It is any function that contributes to accomplishing the Basic Function., (Borza 2011).
❖ Critical Functions that fall along this line are critical to the performance of the basic function

(Washington state departement of transportation 2021) functions which must occur for the BasicFunction to occur or be delivered.

- ❖ One-time functions are those secondary functions that only happen once. (example: Assemble Components) (Washington state departement of transportation 2021).
- ❖ Project objectives: the main task the whole system was built to achieve, e.g.. control traffic. (Borza 2011)
- ❖ All-the-time Functions are broad requirements applied within the subject scope and are not usually directly related to the Basic Function, e.g., Assure Quality.
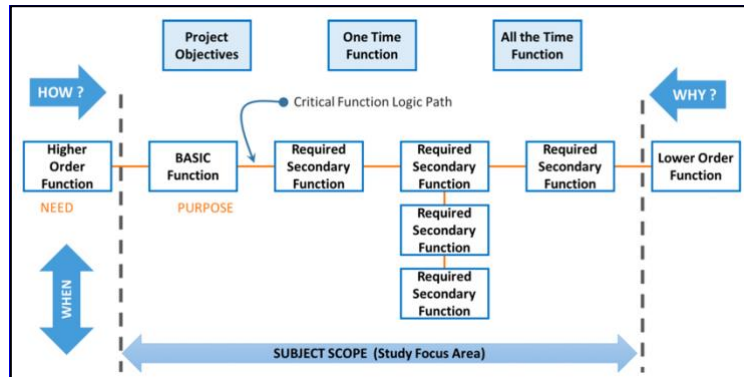
Figure 8: FAST diagram, (Washington state departement of transportation 2021)

The search for the functions that provide the most value that carefully defined aspect of the total life cycle cost with the lowest cost is the goal of value management teams and a critical idea about the thinking process, therefore, multiple approaches can help the team produce function and analyze their value to the whole system, these methods can encourage the critical thinking about the system tasks and their constraints. Methods such as (Borza 2011):

- ❖ Component-Function Mapping approach: Identifying the functions for each system physical component in the assembly, process, service, or system and relevant functions that are mapped into the model.
- ❖ Random Function Generation: Identifying the system functions with no regard to "cause and effect" relationships between them, until the integrated team has collected all the functions that can be presented, then, build the model using the logic tests for connecting the listed functions.
- ❖ Eliminate Harm method: Starting by identifying the harmful function or negative effect that you want to eliminate, the inclusion of harmful functions in Enhanced FAST diagrams uncovers inherent contradictions in the systems.

Characteristics of the FAST diagram:
- ❖ During the analysis phase "When we ask **HOW** we are looking for solutions and moving to lower levels of opportunity. When we ask **'WHY'** we are looking for reasons and moving to higher levels of opportunity." By asking HOW (is this going to do it) and WHY (is it doing it, (Washington state departement of transportation 2021)
- ❖ when one goes from left to right these functions respond to answering "how" questions, from right to left answering "why" questions, (Chamberland 1989)

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- ❖ Asking how the system is being done or why is it being done rather than how can it be done or why should it be done? These questions may be helpful after the original project FAST has been developed, (Younker and CrcnetBase 2003).
- ❖ The FAST Model should be "implementation free", meaning the model should not specify or dictate physical elements or solutions,(Borza 2011).
- ❖ The FAST diagram Keeps models to less than 15 - 20 functions, it is often difficult for the mind to capture and process, (Borza 2011).
- ❖ There is no single "correct" way for creating a FAST Diagram of a product, process, service, or system It can vary depending on:
    - ○ The focus of the analysis – is it high level or 'nuts & bolts.
    - ○ Technology or customer-focused.
    - ○ Objectives of the study in which it is used – cost reductions, process improvement, or technical problem-solving.
- ❖ FAST Diagrams frame all functions in a positive sense. one function can produce another function, or can counteract another. (Borza 2011)
- ❖ The ability to control functions value with several logic paths for each link, figure (9) (Washington state departement of transportation 2021).
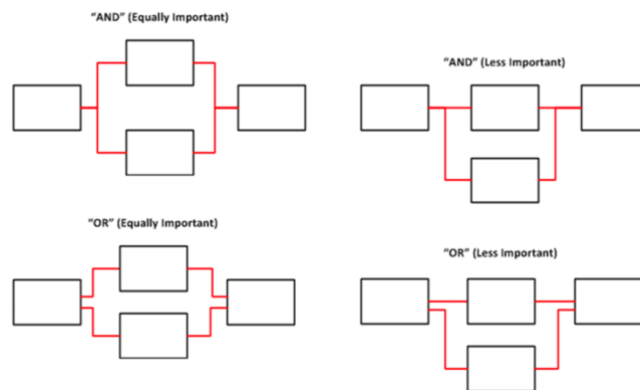
Figure 9: Logic paths of function in the FAST diagram

Enhanced FAST diagram:

The enhanced diagram tries to change a couple of concepts about the normal FAST diagram by trying to improve the following aspects:

- ❖ It allows for the use of negative as a function frame rather than only positive framing, to detect the contradictions between functions and the tasks assigned to them.
- ❖ the Enhanced FAST has a more flexible description of functions. The Action Verb – Measurable Noun two-word format required in FAST is improved to accommodate 'Object-Action-Context", (Borza 2011)
- ❖ The FAST diagram does not have directional arrows between functions. In the Enhanced FAST Diagrams directional arrows are necessary to clarify which function produces or counteracts which other function, (Borza 2011).
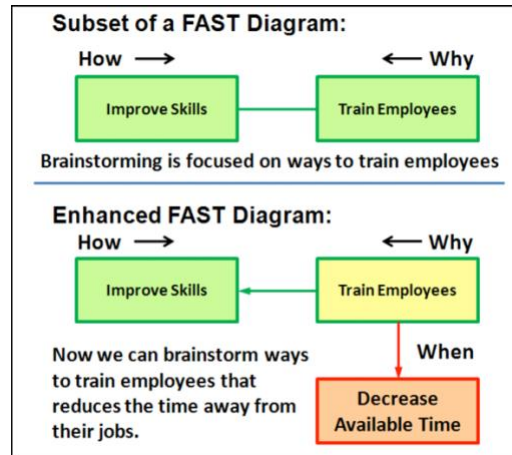
Figure 10: The enhanced FAST effect on function

Value management methods to improve functions allocation:

These value engineering methods can help the team during the function production session to increase the value of functions, therefore, a good understanding of this knowledge of these techniques should be known by the team for an effective and efficient application of the FAST diagram. These methods also are present in the collected theoretical patterns and the interview for confirmation of the function's value importance in the process.

SMART (simple maldistributed rating technique), (Green 1994): The objective is to verify the need to build before the client becomes committed to financial expenditure. The secondary objective is to ensure the clear project objectives which are understood by all the parties involved in the project

- ❖ Identify the stakeholders.
- ❖ Identify the design objectives
- ❖ Construct the value tree FAST.
- ❖ Creativity: The objectives generated are then used as the stimuli for a brainstorming session.
- ❖ Evaluation: The ideas produced in the previous stage are now evaluated in terms of cost and feasibility.

Function resource matrix worksheet, (Washington state departement of transportation 2021): to relate the functions to their cost which gives a better understanding of the solutions and assist in the application of the function/cost process.

- ❖ List the functions within the scope of the project across the top of the form.
- ❖ List parts, major sub-systems, steps of a procedure vertically on the left side of the form with their associated costs determined from the Information Phase.
- ❖ Check off which functions are affected by each item/step.
- ❖ Determine how much cost of each item belongs to each function
- ❖ Add all columns vertically to determine how much cost is allocated to each function.

Theoretical patterns reference review:
The next table presents the theoretical patterns collected from literature with different sources that ensure importance of each aspect in the production of functions, thus, more effective application and knowledge of the FAST diagram method:

Table 3: Collected theoretical patterns

Functions production in FAST diagram (Theoretical patterns)	Reference										
	(Borza 2011)	(Chamberland 1989)	(de Graaf, Vromen et al. 2017)	(Graaf 2019)	(Green 1994)	(Kamrani, Azimi et al. 2011)	(Office of the Deputy Under Secretary of Defense for Acquisition and Technology 2008)	(PRoRail 2015)	(Viola 2012)	(Washington state departement of transportation 2021)	(Younker and CrcnetBase 2003)
The number of functions should be limited, and the redundant functions are removed.	●	●	●			●	●				
The use of "Active Verb + Measurable Noun" functions creation	●	●	●	●	●	●	●	●	●	●	●
Hierarchical decomposition of functional groupings from the top-level functions till the subfunctions	●	●	●	●	●	●	●	●	●	●	●
The use of positive and negative wording in the function phrasing.	●										
Encouraging the team physical sessions for functional allocation, (e.g., brainstorming)	●		●	●							●
Identifying and defining all internal and external functional interfaces.	●	●	●	●	●		●		●	●	●

The use of SMART requirements for effective transition to functions	●		●	●	●							
Revisiting requirements to solve functions issues	●		●	●	●	●	●	●	●			
Enthusiasm of the integrated team			●	●					●			
Free solution wording of functions (more alternatives)	●		●	●		●		●	●			
Understanding the VE concepts for better functional value		●			●				●	●	●	
The use of requirements and design loops			●	●			●					

5.2 Empirical patterns

This chapter will further explore the collection and analysis of engineering practices used by engineers, to identify project functions using the FAST diagram method. Analyzing the practice framework and answering the case study question regarding the key practices done by an engineering/consultancy firm. The empirical patterns of the case study were extracted from questions asked to multiple engineers involved in applying the systems engineering process in their daily work. Questions that give an insight into the mistakes and problems (patterns) the management engineering firms face during the function production phase of the different projects. Patterns involve the multidisciplinary team's depth of theoretical knowledge about the FAST diagram (functional analysis in general), the organizational setup, and the hierarchy with the different responsibilities (the work dynamic).

Next, an explanation of the interviews regarding the personnel expertise in the FAST diagram to establish their relevance to the case study, followed by the analysis of their answers. A summary of the answers is displayed in a table that contains the empirical patterns, in the form of expressive short sentences that can be later compared to theoretical patterns. Aiming to increase the epistemic value of the FAST diagram research while encouraging a new organizational policy or practices to reduce the error and consequently the extra costs resulting from the delay.

Personnel Interviewed:
- ❖ Value-engineer: value engineers are usually concerned with the value of functions and settingset up the teams' sessions for the functional analysis of a project.
- ❖ Two System integration engineers: Integration engineers are responsible for connecting the multidisciplinary project expertise and ensuring the best solution and application of the design process, working with functions of multiple aspects of the infrastructure.

Interview questions:
The interviews involved three engineers separately working for an engineering firm that applies the SE processes as an organizational system framework. Specific key theoretical patterns related to the optimum application of the FAST diagram were translated into questions for the interviews, ensuring the relationship between the theoretical and empirical patterns. The interviews were non-physical (online) due to the governmental pandemic restrictions applied at the time of researching the case study, (reference). The list of questions is as follows:

1. **Open question:** Could you explain the normal sequence of events to create the FAST diagram? when do you start? What are the key steps taken by the team?
2. Is the team usually enthusiastic about the FAST diagram application?
3. Do you use the group brainstorm technique to produce functions?
4. During the production of the requirements, is there attention to making the requirements SMART (specific, measurable, acceptable, realistic, time-bounded)?
5. Are the requirement and design loops used frequently during the production of function? step to resolve functional issues
6. Are the desired and required functions first established at the beginning of the analysis? Do you group and/then decompose the functions?
7. During the creation of the FAST diagram, is there a focus on the "Active Verb + Measurable Noun" rule for creating a function?
8. Is there a focus on the hierarchy of functions during the analysis? High value, low value basic, or secondary functions?
9. Are the redundant functions been identified during the analysis?
10. Is there attention on the idea of free solution wording of the functions?
11. Is there attention to limiting the number of functions? is there attention on the positive or negative wording of the functions during the production?
12. Do you use a Functional Cost Analysis (Function Matrix) to determine the value of each function?

13. is there attention on increasing the functionality and lowering costs of a design component, during brainstorming?
14. During the functional analysis, do you use value management techniques such as (function resource matrix worksheet, SMART (simple maldistributed rating technique) or Functional Cost Analysis (Function Matrix)?
15. **Open question:** How is the pandemic affecting the teamwork in the organization?
16. **Open question:** What would be your solution to the delay problem in the FAST diagram? And in your opinion what can be improved, organizationally, procedures to solve it?

Interview analysis:

The interview transcriptions were explored using quotes and numbers to highlight the important practice steps and establish the connection with the empirical patterns, to give a clear understanding of the practices done regarding the functional analysis. The interview started with the introduction of the case study and a small explanation of the objectives and method used to analyze it (pattern-matching). Permission was asked before the recording of each interview to ensure the privacy of participants' info. There were two types of questions, the first is an open question, to get a better view of the processes and practices applied by the engineers in the daily work, furthermore, asking the participants for their opinions. The second type is yes, no, partially questions, to avoid any confusion in the answers that helps specify the patterns and get a better evaluation.

- The first question is an **open one** to understand the normal sequence of events creating the FAST diagram. Engineers usually start by selecting key points to explore at each session, which is organized by the request of value engineers. These points contain the minimum client goals and the difficult focal points facing the project design team. During the session, each engineer from different disciplines can add their input related to his/her expertise. The inputs are then used in blocks and connections to represent the FAST diagram. As the value engineers explained:
"***Composing a FAST diagram starts with whatever goal is in one of the documents policy documents, what is the higher goal in the whole body for a client? And what are the lower means to fulfill those goals put them in blocks and see if you can go if you can connect them***"

- The pandemic (COVID-19) has introduced new challenges and difficulties to group meetings and communications in several fields and tasks that require teamwork. Online meetings took place instead of physical meetings that would be affecting the quality of the work regarding functional analysis, creating a disconnect between the team. The enthusiasm of the team and especially the team leader has a great effect on the quality of the results as mentioned in (Younker and CrcnetBase 2003). As the systems integration interviewee mentioned: [2] "***what we often do in a project a value engineer is part of the team, and that person is mostly responsible for organizing a couple of value sessions. We first try to indicate what are the focal points of a project. what are the biggest risks? Or do we see a very difficult design with a lot of interfaces or something, and mostly for those focus points? We organize different sessions***".
The value engineer had also another take on the organization of the sessions: [1] "***if you are you're a facilitator trying to create a FAST diagram, and if you have low energy or if there's difficulty in putting in the FAST diagram, or if you don't understand what they're talking about and if you don't get a grip of what they're saying, then there is a chance they won't be satisfied***".

Brainstorming sessions are essential for an optimal functional analysis participatory process in terms of efficiency and effectiveness, to exchange ideas between the different expertise involved. The companies adapted to the pandemic by using online tools (e.g. Mural & Miro), both platforms have apps that allow for integration of the team into the workflow (meetings, planning, actions, progress of the project). Nevertheless, these tools lack the human connections in a simple event such as a coffee break, to discuss ideas, as mentioned by the three interviewees:

[1,2] *"I think the main impact is on the project team itself. You notice that you cannot have the small coffee machine talks where you just ping pong around with ideas"*

The designing team -using SE methodology- is a multidisciplinary team that contains management engineers and technical ones that exchange ideas and establish functions. Although the production of functions is more on the management side, the technical engineers should also add their input to the process. The enthusiasm and the knowledge of the technical engineers can be less than their peers, therefore, extra training and involvement should be given. As mentioned by an interviewee: [1] *"I think the people who work with the FAST diagram or the functions, they are quite enthusiastic. So that's mainly value Engineers and system engineers. But we see that, for example, designers or people designing the construction, they do not feel that same enthusiasm"*

- The SE process model -figure 2- starts with requirements before formalizing the functions, therefore, good attention should be given to correctly assigning them. One of the techniques mentioned is the SMART requirements, the idea of requirements formulation as (specific, measurable, acceptable, realistic, time-bounded). The SMART technique allows for a smoother transition to the. Next stem (functional analysis) The interviewees answered with [3] '*Yes*'.
- The revisiting of requirements and objects using feedback loops is a very important aspect in assuring the systematic approach of SE methodology and the best choice of functions. The answer on this subject was generally positive, with two participants having [4] '*partially*' as an answer and one [4] '*Yes*'. The latter was given by the value engineer who is responsible for facilitating the functional analysis sessions.
- The functional analysis starts by establishing the basic desired and required functions for the project, although, the list of functions cannot be complete in the first session, nevertheless, it gives a good basis for discovering new possibilities. The function production process is bounded by a series of rules that should be followed for an optimum application and known by the team to produce an efficient FAST diagram. Rules such as the "active verb + measurable noun" for creating a function that is worded as a task with no solutions allow for more options to be discovered.
Sometimes the use of passive verbs is also encouraged to find the contradictions between functions. The interview participants are all answered with [9] '*Yes*' for knowing and using such rules/ framework, [9] *"It can be positive or negative"*

During the functional analysis, the hierarchy of the functions is another idea that should always be present in the session, to organize the diagram and explore possible connections between the lower-level functions. Thus, helping also by removing the redundant functions and replacing them during the session.
The answers were positive - [5,8] '*Yes*' - about these aspects and even gave more insight into the functional analysis session planning and the interactions where alternatives are discussed to decide on the best function with the highest value. Removing low-value functions.
Another intuitive but important rule is decomposing and grouping of functions for more clarity of the diagram, therefore, avoiding confusion. The interview answers on the use of these rules during the functional analysis step of projects were positive for all the interview participants, that gave a [6] '*Yes*' as an answer.

- Functions are tasks that should be translated into objects; therefore, more focus should be on the actions that influence the quality of the FAST diagram and the consistent production of functions such as free solution wording e.g.," support load". this idea opens more alternatives for a solution by not pre-defining the functions to give a specific solution. Another important idea that can influence the quality of the FAST diagram during the functional analysis sessions is the limiting of the number of functions by grouping and organizing them in hierarchal patterns for a better transition between the functions while keeping more consistent teamwork. All the interviewees gave positive answers to ideas by replying '*Yes*' for the application of these ideas in their work practices, although, the engineers focus was more on a complete listing of functions without missing any aspect that could be

a "*missing chance*" as the value engineer explained: [6,8] "*preferably they are grouped in the right hierarchy. But in the end, if one of the functions is missing, that's a bigger problem*".
The interviewees reacted with [7] '*Yes*' on the use of free solution wording as a concept to phrase the functions but they acknowledged that sometimes the project has a pre-defined solution that leaves the team with the specific functions that they can use for repeated projects, as the interviewee explained: [7] "*sometimes the solution is already part of the scope. so if the scope of the project is already to create a bridge and a tunnel was not an option anymore, you can't always ask the question, Do we really want this bridge? Because it's already decided*"

- The FAST diagram is used mostly as a value engineering tool to organize and evaluate the functions then choosing the best option with either the lowest cost or the highest function. Many tools are used for the analysis of functions value that is important to the FAST diagram, such as the method of functional cost analysis, function resource matrix worksheet, and SMART. All these methods have a goal of increasing the value of the function that was chosen to be present on the FAST diagram (functional analysis). to cover the whole system or project and lower the number of functions (less distraction). The Interviewees gave a mixed reaction to the use of such methods, the value engineer acknowledges the use of it but [10,11] '*partially*'. the system integration answered [10,11] '*No*' and [10,11] "*And I'm going to say no, but I think value engineers involved with it. It might be done, and if we organized the value sessions*".
- The last two open questions are explained as a part of the conclusion because of the lack of decisiveness in answers and the observational side of the question.

Collected empirical patterns:
The next table presents the empirical patterns collected from the interviews. The numbers refer to the interview quotes in the previous text [x] and their relation to the empirical patterns. The table will also contain the score of each interview question according to the presence of an answer by agreeing or not. The interview scores are then translated to the empirical pattern.

Table 4:Collected empirical patterns & the interview scores

Nr	Empirical patterns	Interview Scores		
		1	2	3
1	Some engineers are more enthusiastic about the application of functional analysis session then others.	◐	◐	●
2	The brainstorming participatory technique is not always used to produce function in a session.	◐	●	◐
3	An effective transition from requirement to functions is done by defining a SMART requirement as a framework		●	●
4	The SE design and requirement loops are sometimes used as a step to resolve functional issues	●	◐	◐
5	The functions are usually phrased as "*Active Verb + Measurable Noun*"	●		●
6	The hierarchal decomposition of multi-level functions of the FAST diagram is practiced idea by the team.	●	●	◐
7	The functions have a free solution wording.	●	◐	●
8	Limiting the number of functions in not always a constraining idea during the session but the redundant functions are removed,	●	◐	◐
9	The idea of negative verb use for a function is applied	●	◐	●
10	An important aim of the team is to increase the value of functions.	●	●	●

11	Value management methods are not frequently used to increase the system value	●	◌	◑

5.3 Patterns Comparison

After researching and listing both the theoretical and empirical patterns, the last step of the pattern-matching method is to compare and deduct the mismatches between different patterns. The aim
Is to solve the main case study research question, that is:
From pattern-matching analysis results, what are the practice changes that can be made to improve the application of FAST diagram and functional analysis?
Both patterns are displayed in the next table, which is the result of both the theoretical patterns and the empirical ones.

Table 5: Pattern comparison

Topic	Theoretical patterns	Empirical pattern	Match
1	Enthusiasm of the integrated team is an important aspect in effective an efficient session.	Some engineers are more enthusiastic about the application of functional analysis session then others.	Partially
2	Encouraging the team physical sessions for functional allocation, (e.g., brainstorming)	The brainstorming participatory technique is not always used to produce function in a session.	Partially
3	The use of SMART requirements for effective transition to functions	An effective transition from requirement to functions is done by defining a SMART requirement as a framework	Yes
4	The use of requirements and design loops	The SE design and requirement loops are sometimes used as a step to resolve functional issues	Partially
5	*The use of "Active Verb + Measurable Noun" functions creation.*	The functions are usually phrased as *"Active Verb + Measurable Noun"*	Yes
6	Hierarchical decomposition of functional groupings from the top-level functions till the subfunctions	The hierarchal decomposition of multi-level functions of the FAST diagram is practiced idea by the team.	Yes
7	Free solution wording of functions (more alternatives)	The functions have a free solution wording.	Yes
8	The number of functions should be limited, and the redundant functions are removed.	Limiting the number of functions in not always a constraining idea during the session but the redundant functions are removed,	Partially
9	The use of positive and negative wording in the function phrasing.	The idea of negative verb use for a function is applied	Yes
10	Understanding the VE concepts for better functional value	An important aim of the team is to increase the value of functions.	Yes
11		Value management methods are not frequently used to increase the system value	Partially

6. Conclusion

Results discussion:
After finalizing the case study research and analyzing the patterns involved, the final question of the case study should be answered. The answers given in this chapter contains finding and personal opinions about the practice changes that should be implemented. The pattern-matching comparison question is:
From pattern-matching analysis results, what are the practice changes that can be made to improve the application of FAST diagram and functional analysis?

To analyze this question and understand the practices usually done during the sessions, two open questions were asked to the participants to get their view on the delay problem and the effects of working in the pandemic time conditions. The questions are:

How is the pandemic affecting the teamwork in the organization?
What would be your solution to the delay problem in FAST diagram? And in your opinion what can be improved, organizationally, procedures to solve it?

The result of the comparison showed the following points:
- Assigning as many physical meetings as possible for the designing team is very important. Barnstorming sessions are the most suitable technique to keep the enthusiasm and optimism in the team, decreasing the time needed to finish the functional analysis and leveling the theoretical knowledge of the participants.
- following the last point, not every discipline involved in the sessions has the same level of knowledge about the processes of the FAST diagram (the interviews showed). Value and Systems engineers are usually more knowledgeable about the FAST diagram than technical ones who usually don't see the benefit of it, therefore, sufficient training of all the teams' participants about the rules and processes of the FAST diagram will increase the productivity and efficiency of the functional analysis. The training should focus on aspects related to the use of requirement and design loops as a consistency check and rule for avoiding the freeze at a process. Also limiting the number of functions and the constant use of value engineering methods for choosing the functions with the highest value will allow for a unified framework and practices of the team members.

- The COVID-19 pandemic has introduced a new challenge for the companies regarding the types of sessions (physical, online), forcing them to adapt to the online collaboration tools (Mural & Miro). Proper training and a good ICT service (license facilitation) are essential for effective teamwork and communication.

Limitation:
- Although the number of interviews was sufficient, yet, it was minimum due to the nature of the research (internal with no contract with an external company).
- The references/research regarding the adaptation and use of the FAST diagram and the functional analysis in the constructions industry is limited, it is more applied as a general methodology.

Suggestion for further research on the subject
- More focus on value engineering techniques to improve the rules that are used in the FAST diagram and functional analysis in general.
- A good number of interviews should be done to get the best results.

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> The paper distinguishes between value management and value engineering on the basis of their underlying assumptions. The traditional approach to value engineering is analysed, and is found to reflect the optimizing paradigm of hard systems thinking. In contrast, the alternative approach offered by value management is based on the learning paradigm of soft systems thinking. While the objectives of value engineering are dominated by cost reduction, the purpose of value management is to develop a common understanding of the design problem and to identify explicitly an agreed statement of design objectives by the project stakeholders. smart value management is introduced as the means by which these ends can be achieved. It is further suggested that this approach enables project managers to exert an increased level of control over the early stages of building design. It also ensures that different interest groups within the client organization are actively involved in the design process, and that they thus 'buy in' to the decisions which are made.

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> The scope of contractors, within engineering projects, is growing and becoming more complex (Locatelli, Mancini, & Romano, 2014). It is changing from making the final design and construction, towards responsibility of the entire life cycle of the project. For these projects, success is not only based on the so called 'iron-triangle; Cost, Time and Quality (Locatelli et al., 2014). According the iron-triangle, a project is a success if it is delivered within time and budget, and in respect of the customer's specifications. The iron triangle focusses on the outcome of a project in time and budget, not specifically on the process towards the outcome. With the growing scope of the contractor in mind, this irontriangle no longer suffices for the success of a project. The growing scope of the contractors ensure that the work packages of the contractor are also growing and more boundaries with stakeholders are addressed.

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> In recent years, reverse logistics supply chain (RLSC) has gained momentum as an environmentally friendly approach that could facilitate in greening the conventional construction supply chains. A perusal of literature shows that the research in the field of RLSC of demolition waste (DW) is in an evolving phase. The improper information sharing (IS) is a serious issue in RLSC of DW, which has not been reviewed extensively. Thus, the aim of this study is to discern the aspects of IS in RLSC of DW and to provide potential future research directions on the topic. To accomplish the aim, the objectives of this paper are two folds: (i) to explore the aspects of IS in RLSC of DW; and (ii) to identify the future research directions of IS in RLSC of DW. A total of 89 articles from five search engines published between 2000 and 2019 were subjected to descriptive and content analysis. The descriptive analysis revealed that most of the reviewed studies were case studies and originated from developed countries. The content analysis found that complex, fragmented, cross-functional and multi-disciplinary nature of the supply chain primarily leads to

improper IS in RLSC of DW. A collaborative network is needed to improve IS, which is facilitated by government and Information, Communications and Technology (ICT) based initiatives. The study makes a significant contribution by building the foundation on IS in RLSC of DW through proposing a conceptual framework. The conceptual framework shows an outline for the organisations in RLSC of DW to formulate their information initiative strategy. This could be considered as the first step to improve IS in RLSC of DW. Besides, the study also acknowledges several paths of doing further research to contribute to the domain under study.

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8. Appendix

A: Theoretical patterns link to interview question

Table 6: Theoretical patterns link to interview question

Questions	Theoretical patterns explanation
Open: Could you explain the normal sequence of events to create the FAST diagram?	Understanding the practical application of FAST diagram and functions allocation.
During the production of the requirements, is there an attention on making the requirements SMART (specific, measurable, acceptable, realistic, time bounded)?	Attention for the wording of requirements for later verification and correct use of FAST diagram to produce functions.
Do you revisit (as a system engineer) the requirements as a step to resolve functional issues?	Identifying possible solutions by revisiting requirements.
Are the requirement and design loops used frequently during the production of function?	The use of feedback loops for consistent and smooth transition between the processes, figure (2)
During the creation of the FAST diagram, is there a focus on the "Active Verb + Measurable Noun" rule for creating function? or do you add third word to the function?	Attention on the wording of functions as free solution.
Do you use group brainstorm technique to produce functions?	Functions production using team session techniques for an effective application of the FAST diagram.
Do you incorporate a functional characteristic of existing system with the functional analysis and allocation?	Integrating current systems functions in the solution for new functions.
Are the desired and required functions first established in the beginning of the analysis?	Starting point of functional analysis as a smooth transition from the requirements. Ensuring the stakeholders interests in the project.
Do you group and/then decompose the functions?	Common systematic approach to the production of functions, creating the FAST diagram.
Is there focus on the hierarchy of functions during the analysis? High value, low value basic or secondary functions?	Common systematic approach to the production of functions, creating the FAST diagram.
Is there an attention on the idea of free solution wording of the functions?	Functions are 'tasks' the system or projects should perform yet they should not include a solution for better alternatives selection.
Are the redundant functions been identified during the analysis?	Common systematic approach to the eliminate functions, creating diagram that is more consistent to the stakeholders needs.

Is there an attention on limiting the number of functions?	Common systematic approach to reduce the complicity and confusion, especially during the presence of multiple primary and secondary functions.
Is there an attention on numbering the functions during the analysis?	Common systematic approach to the production of functions, creating the FAST diagram.
Has the structure of functional breakdown structure **FBS** been developed?	Common systematic approach to allocate the basic functions, creating the FAST diagram.
During the functional analysis, do you use value management techniques such as (function resource matrix worksheet, SMART (simple maldistributed rating technique)?	A common framework to understand the value management techniques that increase the functions.
Do you use the Functional Cost Analysis (Function Matrix), to determine the value of each function? or are there costs assigned to each function?	A common framework to understand the value management techniques that increase the functions.
Is there attention on increasing the functionality and lowering costs of a design component, during brain storming?	A common framework to understand the value management techniques that increase the functions.
Is there an attention on the positive or negative wording of the functions during the production? (It can affect the production of lower-level functions and sow contradictions)	Negative phrasing of functions, e.g., "decrease time" can show the contradictions between functions, leading to better and more alternatives.
Open: Is the team usually enthusiastic about the FAST diagram application?	Working on the FAST diagram requires the integrated team a level of enthusiasm.
Open: How is the pandemic affecting the teamwork in the organization?	The effect of the COVID-19 pandemic on the tools of communication between the team members in an engineering company.
Open: What is your solution to the problem	

B. Interviews:
First interview:

Interviewer: The answer to the next questions is yes, no or partially so yes, no or partially. During the production of the requirements, is there an attention on making the requirements smart? and do you revisit, the requirements as a step to resolve functional issues?

Interviewee (System integration, 1): Yes.

interviewer: Are the requirements and design loops used frequently during the production of functions? Do you go back to the requirement or go forward?

Interviewee (System integration, 1): Yes.

Interviewer: They use this group brainstorming technique for the production of functions?

Interviewee (System integration, 1): Partial.

interviewer: Do you incorporate a functional characteristics of existing system with the functional analysis and allocation?

Interviewee (System integration, 1): Yes. New project Yes.

interviewer: Ok. Are the desired and required functions first established in the beginning of the analysis?

 Interviewee (System integration, 1): Partial.

interviewer: do you first group the functions and then decompose them?

Interviewee (System integration, 1): Yes.

interviewer: is there a focus on the hierarchy of functions during the analysis?

Interviewee (System integration, 1): Yes.

interviewer: Is there attention on the idea of free solution wording of functions? While creating the functions, do you keep that in mind, that the functions should not have a solution?

Interviewee (System integration, 1): Yes.

interviewer: Are the redundant functions being identified during the analysis?

Interviewee (System integration, 1): Yes.

interviewer: Is there an attension on limiting the number of functions?

Interviewee (System integration, 1): Yes.

interviewer: Has the structure of functional breakdown Structure has been developed during the analysis?

Interviewee (System integration, 1): Yes.

interviewer: During the functional analysis, do you use value management techniques such as function resource matrix or SMART?

Interviewee (System integration, 1): Yes.

interviewer: The these are the functional cost analysis to determine the value of each function?

Interviewee (System integration, 1): Yes.

interviewer: Do you assign costs to each function?

Interviewee (System integration, 1): To each function?

interviewer: Yeah. To see what the Coast of function is better than the other? Or is it more for value engineers,

Interviewee (System integration, 1): More for value engineers? I wouldn't know.

interviewer: Is there an attention on increasing the functionality and lowering costs of the design component?

Interviewee (System integration, 1): Yes.

interviewer: Is there an attention on positive or negative wording of the functions during the production?

Interviewee (System integration, 1): What wording?

interviewer: For instance, the literature say that if you use the negative wording of functions, then you can understand the contradictions between functions.

interviewer: Yeah. Is there an intention on the positive or negative wording of the function during the production?

Interviewee (System integration, 1): Yes.

interviewer: So this is the last yes or no question. Is the team usually enthusiastic about the FAST diagram application?

Interviewee (System integration, 1): I would say partial. I don't dare to say yes for everyone. Yeah, I'm pretty sure there are people and suggesting and I'm pretty sure there are people that are like, Oh, OK, but the whole systems engineering of alienating thing in general. So I would say partial.

interviewer: Now for open question, how is the pandemic affecting the teamwork in the organization?

Interviewee (System integration, 1): Good question?

interviewer: Is it bad? Not good. What do you think?

Interviewee (System integration, 1): Ok. I think that obviously we have gone from physical work to team's work, which means that it's more difficult. It has become more difficult to, you know, ask good questions like, for example, you're busy with a task and you need someone quickly. You cannot do that. You're at distance at the same time. I've experienced that it has become easier to set meetings together because usually before the pandemic, we would be like, OK, where are we going to meet? When are you able to copy? And definitely, when are you able to be in Amsterdam? So it was more difficult to arrange like meetings, and now it's easier. But I think when it really comes to teamwork in my experience, it's best to be sitting at one location together and working, and it's way more easier to learn to ask the questions and stuff like that. So I think the pandemic has obviously made it more difficult to do that. Also, when people getting sick or being absent, even when we're allowed to go to the office, if you are basically sneezing, you're not allowed to come. So we are really still figuring things out with hybrid working as well, you know, having as part of the team at the office in a part hybrid. So it has advantages like easier to meet. More flexibility in, you know, working, and it has disadvantages such as being apart from each other and not being able to get a grip on people.

interviewer: Yeah, but for the brainstorming session, what do you think that for the FAST diagram? For something like functions?

Interviewee (System integration, 1): Yeah. We are figuring things out also with visualizations and brainstorming through, for example, mural. I don't know if you know that or Mural app. Those are all like applications you can use online. Everybody can work in them at the same time. So actually, the pandemic helped us to figure out these new tools to use. I think we do pretty well with brainstorming in general through teams and while using an application. I would still prefer, however, to be sitting at the office together in a room.

interviewer: Okay. Okay. So did it bring the enthusiasm a bit down or less?

Interviewee (System integration, 1): Yeah, I can, really. I feel like some people really, you know, have difficulties with the whole working apart from each other because, you know, when you're at the office, you have also small chit chat. I mean. Brainstorming, yeah, you might be at the coffee and still brainstorm. So yeah. Yeah.

interviewer: What would be your solution to the delay problem in the FAST diagram? And in your opinion, what can be improved organizationally procedures? What do you think?

Interviewee (System integration, 1): For creating a FAST during the pandemic?

interviewer: Yeah. Because now there is a delay in production of functions. Yes. So what would be your solution to it from what you see during work, during meetings?

Interviewee (System integration, 1): I would really recommend for the company to set us a license for tools, because currently we do not always have license for these tools like meural and merul, and you need to get them to act and get approval first and to have more focus on online as well as hybrid brainstorming. How to facilitate that. That can be through even training or whatever. But to have like one company. And that's it for that, because I've been in a project where we still are figuring things out, like, how are we going to do that? And we happen to have somebody that it before, but I would like the company to be more proactive in that.

interviewer: Yeah, so that was that. That was the interview, actually. So do you have any comments, any questions or anything?

Interviewee (System integration, 1): No, I hope I was of use, even though I did not really work it fast.

Interviewer: my first question is an open question, and I would like to ask.
Could you explain in a normal situation how the normal sequence of
events to create the fast diagram? What are the steps
taken? when do you start? What are the key steps?

Interviewee (System integration, 2):
Yeah, So what we often do in a project a value engineer is part of the team, and that person
is mostly responsible for organising a couple of value sessions.
And so, we first try to indicate what are the focal points of a project. what are the biggest risks? Or do
we see a very difficult design with a lot of interfaces or something, and mostly for those focus
points? We organize different sessions.
And then, the sessions are prepared by the value engineer, and they are the facilitator of the session,
but it's very important that the facilitator remains sort of objective, so he or she is not too involved in
a certain discipline, so that the balance would be off very much to construction instead of nature.

Interviewee (System integration, 2): So what we then do during those sessions is we come.
First we try to collect all the knowledge within the team from the different disciplines. So,
we already centered a focus point, but then we try to get everyone perspective on it.
And then we really try to formulate what is really the essension or the main objective of the project
or the programme. Actually, what is centered at the intercession.
Then we really try to see what the necessary functions are to get to achieve that objective.
We really try to have the main objective of the project. Then the objective of the focus point.
And then we try to see what are the main issues here or what do
we need to fix and then what? What functions does the system need to fulfil to be able to achieve that
objective?

interviewer:
We will go now to questions that the answer of this question is yes, no or partially

Interviewee (System integration, 2): Ok

interviewer: I will read it and you give me if it's which one is it?
So during the production of the requirements, is there an attention on making the requirements smart?
Specific measurable.

Interviewee (System integration, 2): Yes.

interviewer: Uh, do you revisit the the requirements as a step to resolve the functional issues?

Interviewee (System integration, 2): Yes

interviewer: OK,
are other requirements and design loops used frequently during the production of function or?

Interviewee (System integration, 2): I don't really understand your question, I think. Or
do you mean exactly?

interviewer: In systems engineering there is
like the between the requirement functions and object and objects. There's like

a requirement loop and design loop. Do you use them during the production of functions? Do you go back into the requirements or from the functions to the objects?

Interviewee (System integration, 2): I would say partially.

interviewer: OK.

Interviewee (System integration, 2): It's not a full Yes, it's more yes than no, but. half and half.

interviewer: OK, during the creation of the FAST diagram, is there a focus on the active verb measurable noun rule?
For creation or do you use third word?

interviewer: Do you stay in too words?
Function of too words or do you use 3rd word?

Interviewee (System integration, 2): More too words.

interviewer: OK.
Do you use group brainstorm technique to produce functions?

Interviewee (System integration, 2): Yes

interviewer:
Do you incorporate the functional characteristic of existing system with the functional analysis and allocation?

Interviewee (System integration, 2): Yes

interviewer: All the desired and required functions first established in the beginning of the analysis?

Interviewee (System integration, 2): Yes

interviewer: Do you group and then compose the functions?

Interviewee (System integration, 2): Yes

interviewer: Is there a focus on the hierarchy of functions during the analysis?

Interviewee (System integration, 2): there's focus on hierarchy, yeah.

interviewer: That's good.
Is there an attention on the idea of free solution wording of this of the functions?
That the function should have no solution.
It shouldn't give a solution to.

Interviewee (System integration, 2): yeah, partially.

interviewer: OK.
Are the Redundant functions being identified during the analysis?
During the brainstorm session.

Interviewee (System integration, 2): Yes.

interviewer: Is there an attention on limiting the number of functions?

Interviewee (System integration, 2): Yes

interviewer: Is there an attention on numbering the functions during the analysis?

Interviewee (System integration, 2): And my doubt is, is that it's Not exactly at the Brainstorm. We use Relatics which automatically numbers the function so.

interviewer: OK.
Has the structure of the functional breakdown structure been developed during The analysis?

Interviewee (System integration, 2): Yes.

interviewer: During the functional analysis,
do you use value management techniques such as functional resource matrix worksheet?
Or smart?

Interviewee (System integration, 2): Not always.

interviewer:
Do you use the functional cost analysis function matrix to determine the value of each function?

Interviewee (System integration, 2): And I'm going to say no. I don't know if it's never but hardly ever, I guess.

interviewer: OK.
is it not necessary or Why? Because you said, there's like value engineers. So I suppose that they already work with them.

Interviewee (System integration, 2): Yeah, it might be.
I'm not sure, but I think value engineers really involved with it.
It might be done and if we really organized the value sessions.
We also have like in for example a road expansion. You already have a sort of basis set of requirements and also functions that sort of always apply.
then you really only see what are the the projects of specifics functions that we need to add or that we need to, which are redundant and then not always. There are our value engineering sessions.
Or it's sometimes also considered not necessary, so then it's more straightforward approach to analyzing functions.

interviewer:
is there attention on increasing the functionality and lowering the cost of the design component during the analysis?

Interviewee (System integration, 2): Yes.

interviewer: Is there an attention on the positive or negative negative wording of the function during the production?
Because negative wording, sometimes, they sayin the literature that you can see the contradiction and functions well when you use the negative wording.

Interviewee (System integration, 2): Yeah, I really think partially.

We don't do it always, no.

interviewer: OK.
So this is the last yes or no question
is the team usually into into the enthusiastic about the fast diagram application?
Do you usually go in to start with into the enthusiasm or is it like more?

Interviewee (System integration, 2): Well, partially because uh. Also to elaborate a bit,
I think the people who really work with the FAST diagram or the functions,
they are quite enthusiastic. So that's mainly value Engineers and system engineers.
But we really see that, for example, designers
or people designing the construction, they do not really feel that same enthusiasm, although they
really must deliver their input, it doesn't. Their enthusiasm doesn't really match with the team that
really works with it so.
Yeah, partially.

interviewer: OK,
I have two or three open questions, so how is the pandemic affecting the teamwork and the
organization? How do you think is it?
More is it less? Is it? Is it causing any problems for the FASTdiagram? this is the perfect way to do
it. the pandemic is bit difficult.

Interviewee (System integration, 2): I am not 100% sure if it's also for the FAST diagram.
What I do know is that in the first months of the pandemic we were all a bit like, well, how do we
have to do it? and the brainstorms were either cancels or of lower Quality because of,
we were not used to working online and we didn't really find the good form to do it, but right now I
know all of Our departments actually quite informative switch to being able to do those things online
as well and I know value engineering also switched to online and I think we're quite inventive right
now with the tools that we use and how we can also online make it an interactive session.
So, I think right now the effect is maybe quite small, even. Maybe we even investigated possible tools
even more so.
Therefore, the quality might be improved the the measures that we use might be more effective than
when we did them offline, and I think the main impact is on the project team itself.
You really notice that you cannot have the small coffee machine
talks where you just ping pong around with ideas and I think in the preparation of possession that
might be a little bit of overlap.
I think a lot of people think maybe it's not that important, and so maybe you missed the short
brainstorm sessions to make it even better.

interviewer: OK, so.
many sessions or how long it takes to finish the phase diagram?

Interviewee (System integration, 2): then I will have.
To look at the documentation, I think we have sort of an estimate.
I think it really depends on the on the project itself I think the scope of the
session might also differ on how large the issue is that that we're looking at.
I think in general, what I can see the number of sessions differs quite a lot.
I also think it's not only the sessions, but also some work afterwards to work out the results in
a neat format and people can deliver their feedback on it. And that's not always necessarily done in
a session.
a month or something for
and I think in the case that you don't really organise all the the this the sessions but then.
And you do the very basic functional analysis and then not always. A fast is produced,
and sometimes it's just the functional hierarchy,
but but then you would. Also, you can do it quite fast because you have the basic basis set.

Of functional requirements, but then you will have to go back
like each month or two months just to do an update. So then you have two loops, so then it's not quite time intensive.
Work, but it's stretched over long periods of time.

interviewer: OK.
So for the last question.
What would be your solution to the delay problem in the first diagram and?
In your opinion, what can be improved?
In terms of organisational procedures, what can?
Be improved in your opinion.

Interviewee (System integration, 2): Well, I think the main issue might be that,
uh, what I said earlier about the the different teams working off on it or delivering their input.
I think the.
Boss diagram is quite a difficult concept for people who are not really into system engineering or valueengineering and so therefore people do not always see the benefits and do not always understand
What how it works and.
How it could help them? and what they really need to do? for example, a
failure session, and so I think it it should be. Really, it would be great if there's some sort of
solution to make people understand the FAST diagram, so they project into their own work and in
order to also improve their enthusiasm and their will to work with it and
just handing them over the document and simply explaining or something I don't think it's enough.

interviewer: you don't think it's enough? Just explaining what they did, you mean?

Interviewee (System integration, 2): No, no, I think it's still enough, although you maybe have
a whole process and you come up with a very nice document that you can also show to other projects
.
As an example, I don't see.
It really makes the click for people who do not really understand it and see the benefits. So I think
 there should be something more in order or other people and designers to understand.

interviewer: Yeah, you mean maybe more education about the FAST diagram to the
workers that are not value engineers or system engineers.
Right?

Interviewee (System integration, 2): Yeah, I think so and then.
I think you might have the difficulty of people see it as extra work, additional work, or more
like administration. And if you would have some sort of instruction about it.
Education should be really focusing on the benefit is hash for everyone in the project.

interviewer: Perfect answer actually. So that was my interview.
Do you have any questions?
Any comments, anything you want to know?

Interviewee (System integration, 2): Yeah,
I'm curious what because you used a method of pattern matching.
what is your plan for the the last phase?
How are you going to do the pattern matching and write your conclusions?

interviewer: Yeah, so my idea is that I first based my questions on theoretical patterns.
And then I see which \ where is the problem in the whole situation. So I tried to find weak points
in the working of the FAST diagram.

And then try to see what are the things that the employees doing wrong
or not implementing right from the literature. to compare them and see with the analysis.
Which point they should be focused on?
So that's the idea behind it.

Third interview:

Interviewer : So my first question is an open question, could you explain for me the normal sequence of events to create to create the first diagram? When do you start, when what are the steps taken?

Interviewee (value engineer): For me, it is a sort of logical start of every project I do in order for me to make sense of what is the goal and the aim of the project. What are what is the higher goal in the whole body for a client? And what are the lower means to to fulfill those those goals and to get a bit of a bit of an understanding of the of the whole situation and the structure and the approach? And there's no. It would be a way to to apply to the. Only if it is for myself, I will use it in the beginning of the project. And the way of composing a FAST diagram for me starts with Whatever goal is in one of the documents policy documents, most of the time I just try to select one or more, just put them in in blocks and see if you can go if you can connect them. of course, by asking the questions why and how so? Every why question, you can go a little bit to the left in the diagram, I probably have question you go to the right. So that way you can go from side to side trying to get a get a full overview of all the illegals in the in project.

Interviewer : Ok. So do you always use the first diagram as a method or do you have maybe other methods? Do you use?

Interviewee (value engineer): I think I always use the first diagram, but I don't always call it the first diagram. I would guess also, you can also make sort of a structure. And so there's another theory of the in Dutch. It's called Toolan in Spanish network, which is a network of goals and means, our activities, which is sort of another theory aside from from value engineering. But in the in the end, it's kind of the same. So there's also the do you call it? To go and try something like that, so there's multiple names for it, but for me, it's just a way of making sense of all the goals and all the activities that are needed to reach those goals.

Interviewer : So just to get an understanding of the whole project.

Interviewee (value engineer): So that's that's for myself what I use it for. But sometimes I also notice and that's the whole project the client or the project team is not really aware of what they're doing contributes to the to the higher goal. And then I use it also sometimes to to get some sort of to use it to to improve them. How do you say it working together within the within the group?

Interviewer : now the questions, the answer of the next questions will be yes, no or partially. so during the production of of the requirements, is there an attention on making the requirements smart? And it means specific, measurable, acceptable, realistic time bounded.

Interviewee (value engineer): What requirements do you do you mean ?

Interviewer : Requirements of the project?

Interviewee (value engineer): That's on track or out of project, we execute the

Interviewer : Project that you execute. The requirements are the clients needs right? The project.

Interviewee (value engineer): And I don't think I fully understand. Could you elaborate a bit on that?

Interviewer : Yeah. the literature says that the requirements in systems engineering, as you know, it's like requirements functions then objects. So in the requirements phase. do you make sure that it's, uh, smart like, the wording of the of the requirements? Is the phrasing of the requirements smart? specific, measurable, acceptable, realistic or time bounded?

Interviewee (value engineer): I tried to, but it doesn't always work, and it takes time, and sometimes it's not always necessary.

Interviewee (value engineer): Well, it would be better to always have them smart yet.

Interviewer : do you revisit as a system engineer? the requirements as a step to resolve functional issues. If you have an issue with the functions, do you go back to the requirements and see What is the issue? how can I solve it?

Interviewee (value engineer): No, not specifically in that order.

Interviewer : Are of the requirement and design loops used frequently during the production of functions?

Interviewee (value engineer): They repeat that one

Interviewer : are of the requirement and design loops used frequently during the production of functions. So in this, as you know, a system engineering, you have that requirement loops between the functions and requirements, and you have also design loop between the function and the objects. And so do you use it usually during the production of functions.

Interviewee (value engineer): Yeah, I think it's both ways. So what you see in projects that it's not usually this one phase and then it's the end and you go into the next phase. Yeah, it's more you do it in cycles. Oh, exactly. You start with reclaimed phase and you go into the function objects and then you have to go back sometimes to the present phase for maybe a function phase. So you can you can make multiple iterations., at least for me, that that works.

Interviewee (value engineer): I'm not sorry. I'm not sure if that's a yes or no.

Interviewer : It's partially right.

Interviewee (value engineer):
I guess. Yeah, yeah.

Interviewer : During the creation of fast diagram, is there a focus on active verb, measurable noun rule for creating functions? can you repeat it, for FAST diagram, for the functions phrasing that is like a rule, active verb and measurable. do you keep this in mind?

Interviewee (value engineer): Yes, I found out that it's really important to use that that type of structure for functions, because if you don't do it, then it will be. It won't. It will be passive. Yeah, if you don't use an active verb. So, yeah, for me, that's really important.

Interviewer : Actually, I have a question about the passive and positive. I will ask you about it. Yeah. Do you use the group brainstorm technique to produce functions or do you do it alone or everyone different? I heard from Pamela that there is latex, uh, latex use latex and relatives.

Interviewee (value engineer): Yeah, I use phone, but I see it as a as a group technique as well to to create a fast diagram. Yeah. So sometimes, as I explained before, I do it for myself, just for myself to get some understanding of the whole project. Yeah, but it can also be a tool to improve the whole group functioning. Yeah, the whole collaboration process. Yeah. And in that way, it's really interesting to use that for brainstorming. Yeah.

Interviewee (value engineer): Incorporate you do it with, you know, with the Post-its putting it on a map and then moving down a bit?

Interviewer : That's one, that's the best way, actually. all the literature says that the only the best way is the brainstorm session for the production of functions. So that's why

Interviewee (value engineer): Sometimes I try. If I have a fellow engineering session to to save time, I will create a fast diagram by myself on beforehand. Yeah. And that doesn't really work, because the people who are there participate in the session, they don't really understand the diagram if they or they don't want to accept. How it looks like. Yeah. So making them with all the participants, it's really the best way, but sometimes it's just not there's not enough time. Yeah. So if you had four hours for fellow engineering session and you have to save time sometimes, and this could be a possible solution, but it's not not ideal.

Interviewer : Oh, so it's partially between. Sometimes you do it sometimes you dont.

Interviewee (value engineer): sometimes I don't. that's true, even though I want to, but sometimes there's not enough time, so I have to choose for a more pragmatic way.

Interviewer : So the next question, do you incorporate the functional characteristics of existing system with the functional analysis and allocation? Do you, uh, if you have existing system, did you do you incorporate it directly in the the first director? And the functionality of that.

Interviewee (value engineer): Yeah. Partially, but more as a check.

Interviewer : Oh, good,

Interviewee (value engineer): Because you also have to check for yourself and with the client. Do you also want this function to be still be part of the future system? Yeah. Okay. Sometimes you don't. So you can you can ask, do you really want this bridge to allow ships to go underneath it all the time? Yeah. Or only smaller ships, for example. So that could be a question you can ask to ask the client.

Interviewer : Okay, so it depends on the client himself.

Interviewee (value engineer): So, you know, you should always ask it. You should always ask it.

Interviewer : Okay. So are the desired and required function functions first established in the beginning of the analysis?

Interviewee (value engineer): You tried to, but you always discover new functions. Yeah, yeah, that's part of the creative process. Yeah.

Interviewer : Yeah. And do you group then composed functions? You try to group functions.

Interviewee (value engineer): so that's part of the structure of the FAST diagram to try to to group functions.

Interviewer : So is there a focus on hierarchy of functions during the analysis?

Interviewee (value engineer): Good question. there is no there is a hierarchy in the FAST diagram, so there is the higher goals and the lower goals. But I wouldn't say that's that's the main focus. No, I would rather be complete in having all the functions and having them this way in a correct way.

Interviewer : So for you, it's more about having the complete functions list of functions than the yeah, OK.

Interviewee (value engineer): And preferably they are grouped in the right hierarchy. But in the end, if one of the functions is missing, that's a bigger problem.

Interviewer : Yeah, exactly.

Interviewee (value engineer): Yeah, it's a problem or an opportunity missed. Yeah.

Interviewer : Is there an attention on the idea of free solution wording of the functions? Do you keep it free solution?

Interviewee (value engineer): Yeah, , I try to. Yeah, that's good. Yeah.

Interviewer : Okay, in the literature, they said that, yeah, this is it should be free world free solution like it doesn't have solution, it should just like give a task.

Interviewee (value engineer): But sometimes the solution is already part of the scope. so if the scope of the project is already to create a bridge and a tunnel was not an option anymore, you can't always ask the question, Do we really want this bridge? Because it's already decided? But then there's also already a solution where is about the tunnel or about the bridge? But then the question should be how high is the bridge then? The functions are focused on the bridge, which is which is fine. You cannot always question them again and again.. So sometimes there could be a solution.

Interviewer : The redundant functions been identified during the the analysis. Do you identify the redundant functions that one that lists useful or?

Interviewee (value engineer): Yeah, yeah, that's really nice if that happens. So if you ask a question, do we really want this to fulfill this function, for example? Do we really want to maintain the bicycle path two metres broad?

Interviewee (value engineer): Or can it also be a bit smaller? And if you can ask those questions, then you're getting to the point of belief that the value of a of a functional analysis. Yeah.

Interviewer : And that's why brainstorming is also important in this kind of difference..

Interviewee (value engineer): You're good because you can ask those questions. Yeah. And they can make those decisions by myself.

Interviewer : Exactly. Yeah.

Interviewee (value engineer): Uh, sometimes it helps to identify the redundant functions. By saying how much they cost? Yeah, exactly. It costs. So if you ask something, do you if you have someone, do you want this function, then they say. And if you ask them, Do you want this function knowing that it will cost you two million extra? Yeah. Then we'll say, Oh no, well, then I'd rather not. Yeah, yeah. Yeah. So that could help. Yeah. Yeah.

Interviewer : So is there an attention on limiting the number of functions?

Interviewee (value engineer): no, not really. Okay.

Interviewer : is there an attention on numbering the functions during the analysis? Do you know all the functions?

Interviewee (value engineer): No, There's no need for. If you put them in a diagram, it could be useful if there's really a high number of functions. For example, more than 20. But I don't normally use the numbers.

Interviewer : Yeah, because in the literature, they say the ideal is 15.

Interviewee (value engineer): Ok. Yeah.

Interviewer : The next question during the functional analysis, do you use value management techniques such as function, resource metrics worksheet or smart? what are the values of each function?

Interviewee (value engineer): and the question was if I use those?

Interviewer : Yeah, exactly. The Function Results Metrics worksheet for instance, or the smart technique?

Interviewee (value engineer): Yeah, I think. And. I'm not really sure how they look like, but I think the function resource matrix is something like. The function allocation

Interviewer : Matrix, yeah, this explains the value of each functions and see which one is better on which one is that it's more suitable for the project.

Interviewee (value engineer): Yeah, I think. Yeah. Sometimes I use them.

Interviewer : do you use the functional cost analysis, functional function metrics to determine the value of each function?

Interviewee (value engineer): Yeah. So as I explained before, sometimes it's really useful, especially if one of the aims of value engineering is to reduce costs, which most of the times it is. Yeah, yeah. Shouldn't be. But sometimes that's a reason to do value engineering study. Exactly.

Interviewer : The value engineering is to find the best option, right? it's like the highest function with the lowest price?

Interviewee (value engineer): No, could also be there function with a high price.

Interviewer : Oh, yeah,

Interviewee (value engineer): Yeah, it's in the end it's about the value. So you could add more functions with no costs. You could. And the lead functions with high costs. And it's not always about cost. So it could also be a functions with the high CO_2 emission. Okay. Functions that require a lot of capacity in terms of people dying.

Interviewer : So you evaluate those functions and then you see the value, then you decide if it's OK for the project or not, depending on.

Interviewee (value engineer): Yeah, not by myself, but with a group. I think that's really important, that's a value engineering that you don't make the decisions yourself. Yeah, because most of the times

you are not a project leader as a value engineer for supporting the project team. Yeah. So you try to give them the insights they need to make those decisions. that's the best part of value engineering sessions where they realize like, Hey, why are we actually doing this this? It doesn't really add much to the project. Maybe we should lead it. Yeah. Or if they see a chance to increase the value with little to no cost. that's what you do is for us, a failure in generic if something like that happens.

Interviewer : Is there an attention on the positive or negative wording of the functions during the production? Because, again, the literature says that if you use also, uh, negative wording, it can also show you the contradictions between between the functions and, uh, as you said, uh, why do you use this function? So do you

Interviewee (value engineer): Have an example of a negative function?

Interviewee (value engineer): Would it be something like to prevent or to decrease or?

Interviewer : Yeah, I think decrease available time for instance.

Interviewee (value engineer):. Yeah, indeed. Could could give some contradictions.

Interviewer : Do you use it? Yeah. Or just active verbs?

Interviewee (value engineer): yes, can be positive or negative. Yeah.

Interviewer : So for the last. Yes or no question, is the team usually enthusiastic about the FAST diagram application?

Interviewee (value engineer): Yes. But depends really on how you organize it, because you're also a facilitator.

Interviewer : Yeah. Is it also for the other engineers or is it more enthusiasm for the value engineers? Maybe it's something.

Interviewee (value engineer): Yeah. And certainly for me, it's fun to do because I like to to to get structure, to projects. The goals and the means and everything. But surprisingly, for a lot of other, more technical involved people, it's also really nice to see how it works. But yeah, it's really different if you are you're a facilitator trying to create a FAST diagram, and if you have low energy or if there's difficulty in putting in the FAST diagram, or if you don't really understand what they're talking about and if you don't get a grip of what they're saying, then there is a chance they won't be satisfied. Yeah. But it really depends on the type of facilitation. Ok. Because in most of the times, it's not something I create, and I send it to them, and then they are happy. Most of the time it's it's about the workshop trying to create it together. Yeah. And then using it. And most of the times they are quite satisfied with with the workshop. Yeah. And then there's still then there's a chance that after the workshop, you don't use it anymore. And though they're satisfied with the first diagram.

Interviewer : Oh, so you don't use it.

Interviewee (value engineer): Sometimes it just ends there, and sometimes that's fine.

Interviewer : so now for the open questions, I have two open questions. How is the pandemic affecting the teamwork and organization in the organization?

Interviewee (value engineer): What makes it more difficult? Yeah, especially as I said, if you tried to do a workshop with and with putting in Post-its, that's totally different. We use the online collaboration tools like mural or mural. which is quite OK, but it's not the same.

Interviewer : Can you work together at the same time on on this, uh, tools?

Interviewee (value engineer): Okay. Yeah. it's a digital whiteboard. Ok.

Interviewer : So how many? How many sessions or how long it takes to finish the first diagram?

Interviewee (value engineer): Usually it's never finished.

Interviewer : Yeah, there's always something to add.

Interviewee (value engineer): There's always something, but there's some point where you accept now it's OK, we can use it. I would say. you can already have one finished in an hour or two hours. Yeah, but then it's quite simple. And it can also take multiple days.

Interviewer : It depends on the complexity of the

Interviewee (value engineer): Project, depends on complexity and sometimes you. You need some, some time off to think about it. Think of the weekends. and I'm sure you're stuck. You can't get any further. And then you just need to go away, walk away and continue the next day. Yeah.

Interviewer : And so you don't miss any functions. So.

Interviewee (value engineer): Yes, exactly, because you need to have a clear mind and then check if everything's there. Yeah. So if you really want to have it, well, it could take a few days in total. So that's. And could cost you a few hours spread out over several days or even weeks.

Interviewer : Ok. So the last question, what would be your solution to the delay problem in the first diagram and in your opinion, what can be improved organizationally procedures? What what's your opinion about it?

Interviewee (value engineer): What did you say to the delay problem?

Interviewer : Yeah. The first diagram, because like my thesis is that about the delay in the first diagram and the problems facing engineers during the production of functions. So how would you solve it in your organization or?

Interviewee (value engineer): Can you explain a bit about the problem or what what is the delay of of of the first diagram?

Interviewer : As you said, , sometimes you get stuck and sometimes there is noclear view of What you should do, and if you include it already, all the functions or not, what would be your solution to the as a procedure in an organization?

Interviewee (value engineer): to be honest, I don't think it's a problem if you get stuck. Sometimes it's just it just happens, and it means you're getting to the core of the problem,

Interviewer : Does it cause any delays sometimes?

Interviewee (value engineer): Yeah, it could be could be a bit of delay, but at the end it will hopefully get a better project.

Interviewer : Yeah, that's my question, actually. Those delays? How what is your solution to prevent those delays? What what could be one thing that you said, if we do this, then maybe it would go smoother the process.

Interviewee (value engineer): I think but that's quite an open door. Yeah. If the people who are participating in the workshop are well prepared. Ok. But for example, literature your fast,

Interviewer : You mean literature from literature

Interviewee (value engineer): Or no, no. So, for example, the first diagram could be composed of several systems. So one is more about, for example, if you look at the dyke as an infrastructure project, it could have one of the functions to to prevent flooding. But that's more kind of a technical question. So the one in that is responsible for the technical part of the project should be prepared. It's about why and how are we preventing floods? that's kind of done some homework in preparation for a workshop. Yeah. There's also other things, for example, more about the ecological value of of a dike. Yeah, and that's Marty Ecologist. And so that's the first thing I said, if the right people in the workshop that know what functions there should be in the project. Yeah, and they should be prepared to to put in the answers and then there should be a good facilitator that is able to transform the technical knowledge into easy, accessible information in functions.