Applying Systems Thinking for Early Validation of a Case Study Definition: An Automated Parking System

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***Abstract*—Case study research and industry-as-laboratory research are well-known research methods in industry–academia collaboration research projects. Defining a case study well in the early phase of an industry–academia complex sociotechnical and data-oriented research project is crucial for success. This success can be measured by the Company's active participation and sharing of all data needed for the research project. In this paper, we apply systems thinking and its tools to validate the Company's need in an early phase to define the case study in the research project. We use systemigrams for early validation. The foundation for the systemigram is system thinking tools. These tools include stakeholder analysis, context diagram, and Customers, Actors, Transformation, Worldview, Owner, and Environment (CATWOE) analysis. Systems thinking and its tools aid in communicating and sharing a common understanding of the Company's case study and support further exploration of the value proposition for the Company's actual needs.**

***Keywords*—early validation; systems thinking; CATWOE analysis; systemigram; company's need; visualization.**

I. Introduction

A lack of available land and a need for more parking places, especially in urban cities, triggers the need for an Automated Parking System (APS) [1]. However, the APS fails mostly for two main reasons: when the system is used at a high rate and when the end-user is unfamiliar with it. In addition, the APS fails due to some mechanical failures[2][3]. The failure rate of an APS is higher than that of the traditional system. Thus, there is a need to increase the reliability of APSs [4].

In this paper, we investigate the application of systems thinking to validate the Company's need in an early phase as part of defining the case study within the harvesting value from big data and digitalization through the Human Systems-Engineering Innovation Framework (H-SEIF 2) research project. Defining a case study well during the early phase of a complex sociotechnical research project is crucial for the success of a research project. This success can be measured by the Company's participation and data sharing. Data sharing is an essential factor in this research project. We systematically analyze the needs and investigate how external forces affect the project's development [5].

1) The case. The H-SEIF 2 project is a research project aiming to enable data-supported early decisions in the early design phase of the New Product Development (NPD) process. Today, an enormous amount of data is available. With the right approach, suitable algorithms, and structure, Norwegian companies can use big data to provide a decisive competitive advantage in the international market. This research project is an ongoing project that investigates how companies that deliver complex systems can streamline their innovation and NPD processes by using big data and digitalization more effectively [5].

2) The Company. The Company is small and medium-sized enterprise that delivers APSs, including maintenance, primarily for land developers and building owners. The APSs include fully and semi-automated car parking systems. The Company is transitioning from selling to developing, producing, and marketing. Their systems are not designed with enough sensors to achieve proper condition monitoring, and they require proper data management. Company management believes that other parking systems are far behind this solution.

The Company has stored data, also called big data. Big data refer to datasets whose size or complexity exceeds the capability of current or conventional methods within the Company. However, the challenge for companies is to explore value from their stored big data [6]. The application of big data will increase the reliability of APSs by making more data-driven decisions for the early design phase within the NPD and maintenance processes [7]. The paper reminder is as follows: Section II illustrate the study's research method. Section III shows systems thinking application in a case study. Section IV provides a thorough discussion, and ultimately Section V wraps up the study with a conclusion.

II. Research Method

A. Case Study Research

We use case study research, as we use industry-as-laboratory research during the research project [8][9]. Case study research includes the following three steps: defining the case study well, selecting the design, and using theory in design work [9]. In this paper, we focus on the first step through applying systems thinking. A case study usually includes multiple units of analysis. We collected mainly qualitative data. The qualitative data include direct observations, participant observations, open-ended (nonstructured) interviews, and physical artifacts.

The direct and participant observations resulted from the authors as researchers involved in a real-life context by participating in events and meetings within the Company-of-Interest. We also conducted open-ended interviews as part of the observation and part of the workshops we performed with the Company. Moreover, we identified and collected stored data within the Company as physical artifacts. These data were downloaded by the Company's employees and provided to the main author of this paper.

Having different sources of evidence permits us, as researchers, to investigate and reinvestigate the consistency of the findings from various sources of evidence. Furthermore, we can converge these pieces of evidence, also called data triangulation, to increase the robustness of the results [10].

B. *Checkland's Soft Systems Methodology*

Applying systems thinking in a case study within the industry-as-laboratory enables soft systems methodology (SSM) and supports systems engineering. Boardman et al. (2009) [11] argue that systems thinking is the foundation of systems engineering, SSM, and applied complexity science.

Figure 1 depicts Checkland's SSM. We modified the methodology to be iterative, excluding the phases between the steps and emphasizing that there was no one right path. Further, we use the systemigram as a conceptual model, structured text as the root definition of relevant systems, and dramatization and dialogue as a comparison of steps 2 and 4. This modification was inspired by Sauser et al. (2011) [12], who called the SSM that includes those modifications Boardman's SSM (BSSM).

SSM allows for individuals' different perspectives and different desirable outcomes of the case study. In addition, SSM bridges the real world and systems thinking [12]–[14]. The SSM consists of the seven steps visualized in Figure 1. Steps 1 to 7 are repeated until consensus is reached among the individuals involved in the in the case study. In other words, the process including the steps is repeated until the Company's need as part of the case study definition is verified and validated.

III. APPLYING SYSTEMS THINKING METHODOLOGY IN A CASE STUDY

There are several definitions of systems thinking. However, Barry Richmond, one of the leaders of systems thinking, emphasizes that systems thinkers look at the tree and the forest simultaneously [15]. In this context, the tree is the Company, and the forest is the H-SEIF2 research project as the project includes other companies. We investigate the similarities and synergies between those companies further during a co-creation process. In this paper, we adopt Arnold and Wade's definition of systems thinking: "Systems thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviors, and devising modifications to them in order to produce desired effects. These skills work together as a system" [16].

To get a better understanding of the context, we describe the system. Furthermore, we define system boundaries with a context diagram. We then identify the stakeholders and their interests in a stakeholder interests map. We use systems thinking tools: CATWOE analysis and systemigram.

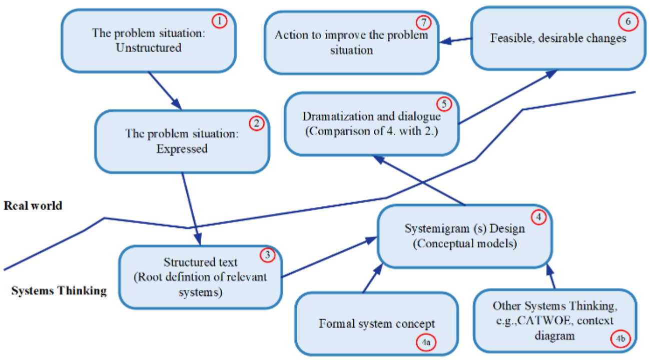

Figure 1. Checkland's soft systems methodology (SSM) based on [12]–[14].

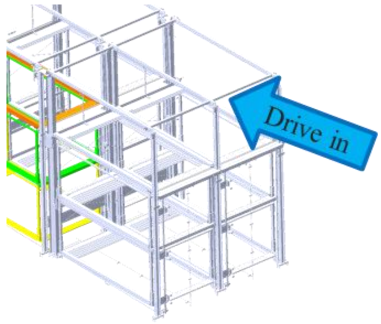

Figure 2. The SOI: the semi-automated parking system.

A. *Description of the APS*

The APS is a complex system due to its multiplex hardware and people's interactions with the system [4]. Problems that occur include not retrieving the right car or no a car at all. Figure 2 shows the System-of-Interest (SOI): a semi-automated car parking system (garage). Figure 2 also depicts a drive-in indication. The car entrance can be a straightforward or inclined plane. The SOI has different configurations. These configurations include different heights, breadths, and depths. The car entrance and the SOI's configurations depend on the building and its architecture. In addition, the SOI includes many parts, such as the gate, control unit, platform, wedges, and so forth.

B. *System Boundaries*

We can understand systems in the context within their environment [17]. The system context helps us to understand the openness of the system. Figure 3 depicts a context diagram for the SOI.

The context diagram illustrates three variables:

1) *Controllable variables* are variables in which we identified the SOI. Having the SOI within the innermost circle means that it is necessary to act sufficiently to achieve the needed outcome.

2) *Influencing variables* are uncontrollable variables that we can influence. We identified the critical stakeholders within the influencing variables. The critical stakeholders are Company management, land developers, building owners, suppliers, local authorities (communes), maintenance personnel, development team, and car owners. We discuss the stakeholders more in the following subsection.

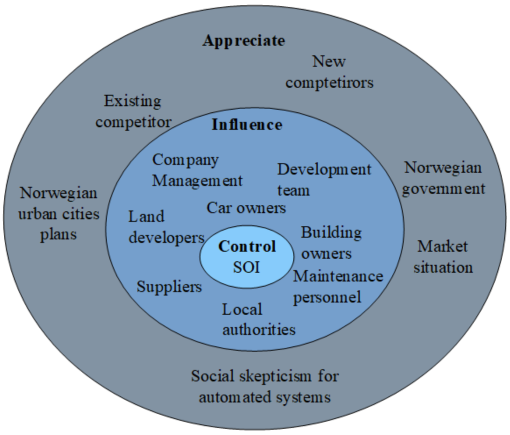

Figure 3. Context diagram of the SOI.

3) Appreciating variables are uncontrollable variables that we cannot influence; thus, we need to appreciate them. The *appreciating variables* include the following:

a) *Existing competitors*. To date, there has been only one competitor in the Norwegian market.

b) *New competitors*. Any new competitor can emerge and enter the market. We included new competitors, although the barrier to entry makes that problematic.

c) *Norwegian urban cities plan*. Norwegian cities have their own development plans, including construction of new buildings and the architecture of old and new buildings [18].

d) *Market situation*. The market situation is crucial, as many Norwegian cities (including Oslo) aim to have car-free downtowns [19]. In addition, the Norwegian market is part of the global market and is highly affected by it.

e) *Norwegian government*. The Norwegian government is responsible for existing and future regulations and standards. The regulations include which level of authorities have the local authorities, also called communes.

f) *Social skepticism* toward automated systems. These automated systems include fully and semi-automated parking systems. Social skepticism is one of the challenges facing the SOI. Car owners may get the wrong car or no vehicle. Thus, increasing the system's reliability is necessary to improve social acceptance. Using big data analytics, including two different data sources to monitor and maintain the SOI, is crucial.

C. Stakeholders and Their Interests

Figure 4 shows the critical stakeholders for the SOI. The SOI in the middle of the figure. Furthermore, we connected the essential stakeholders with the SOI with two types of arrows.

The first type is a solid line and arrow, indicating an intense connection and a strong influence or interest in the SOI. The dashed arrows and lines indicate a weak association between the SOI and the stakeholders(s) and a weak influence on or interest in the SOI. For instance, we identified a weak connection between the government and the SOI, which has regulations, safety, and rules as their interest in the SOI. The government makes the regulations and standards for the systems, including the SOI. However, the government is not involved and does not strongly influence the development process. Thus, we chose to identify this relationship as a weak connection. Furthermore, we identified an intense relationship between the SOI and the following stakeholders: Company management, the development team, maintenance personnel, land developers, building owners, and car owners. This strong connection results from high involvement or influence in the SOI and its development process.

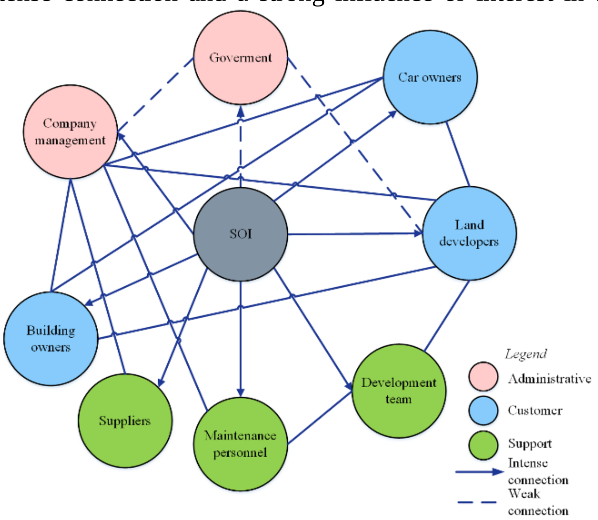

Figure 4. Stakeholder interests map.

We also identified relationships or connections among the stakeholders. For instance, there is a strong connection between car owners and Company management, as car owners are the end-users of the SOI. We present an intense relationship with a solid line between building owners, land developers, and Company management. The Company sells its SOI primarily to land developers. However, the Company also sells its SOI directly to building owners or land developers. Table I lists the stakeholders and their interests.

TABLE I. STAKEHOLDERS AND THEIR INTERESTS

Stakeholder	Interests (why)
Government	Urban city development, including building new buildings and car-free downtowns. The government has the authority for regulation and standards for the SOI and includes the Norwegian Competition Authority
Company management	A reliable SOI as the traditional parking system, customer satisfaction, profit maximation
Land developers	Operating Expense (OPEX) and Capital Expenditure (CAPEX)
Building owners	Operating Expense (OPEX) and Capital Expenditure (CAPEX)
Car owners	Availability of parking spots and reliability of the SOI (getting the right car without any damage at the right time)
Suppliers	Maximize profit by winning contracts and satisfying the Company, which is the supplier's customer
Maintenance personnel	Accessibility and usability of the SOI to conduct maintenance
Development team	Accessibility and usability of the SOI for car owners and maintenance personnel or anyone who uses the SOI

D. CATWOE Analysis

Customers, Actors, Transformation, Worldview, Owner, and Environment are called CATWOE. CATWOE analysis is an essential tool for understanding the different stakeholder perspectives. This understanding is the foundation of the systemigram that we present in the following section.

The CATWEO analysis tool aids in constructing the root definition of the proposed system [20]. This tool also provides an understanding of what the Company wants to achieve with the stored data, alongside their need as a case study. In addition, the CATWEO analysis identifies the problem areas and suggests how the proposed solution could impact the Company and its critical stakeholders.

We apply CATWEO analysis to the two main critical stakeholders in the case study: Company management and maintenance personnel. The results are shown in Table II and

Table III, respectively. The CATWOE illustrates the different aspects of the two main critical stakeholders. These different aspects show the different abstraction levels of the Company's need as part of the case study in the H-SEIF2 research project. Thus, we use the CATWOE analysis as a foundation of the following systems thinking tool: a systemigram.

TABLE II. CATWOE: COMPANY MANAGEMENT

Aspect	Description
Customers	Company management
Actors	Partners, suppliers, maintenance personnel
Transformation	Increase the reliability of the SOI
Worldview	H-SEIF2 research project: value from big data (provide data to the project) Maximize profit
Owner	Company management
Environment	Urban cities

TABLE III. CATWOE: MAINTENANCE PERSONNEL

Aspect	Description
Customers	Maintenance personnel
Actors	Suppliers, Company management, car owners
Transformation	Maintenance process and method
Worldview	Increase reliability and availability of the SOI
Owner	Department heads of service and maintenance
Environment	The Automated Parking System (APS), building, cars, traffic density, weather, city infrastructure

E. *Systemigram*

A systemigram, also called a systemic diagram, is a graphical visualization of the Company's need in terms of storytelling [13]. Using a systemigram aids in communicating understanding of the Company's need. The Company's need represents the surface of the problem definition, as well as the Company's case study in the H-SEIF2 research project. We developed a systemigram based on the analysis and discussion in the previous subsections. The systemigram represents the Company management's and maintenance personnel's perspectives, focusing on the SOI and Condition-Based Maintenance (CBM) system, CBM also seen as the System-Of-System (SOS).

The systemigram, showing the case study based on the Company's need, is visualized in Figure 5. The flow for the systemigram is from the top left to the bottom right. In the upper left is the Company management who presents the SOI for the systemigram, where the primary goal is at the bottom right, which is to maximize business viability. The systemigram is sorted into two main categories with two colors. The first category is the mainstay in dark gray blue. The other main category is big data, in light blue. We aim to have an overview of available stored data and possible needed data for the Company's proposed system (request) within the Company's case study: the CBM system (SOS).

The mainstay is diagonal and presents the central message of the systemigram. The mainstay can be read as follows: "Company management owns the SOI that comprises the NPD process that constitute sensor(s) that allow CBM system implementation, which permits observation of anomalies that aids mechanical failure detection and prediction in real-time which allows continuous monitoring of the SOI through a dashboard that maximizes business viability." Business viability includes many other nodes: increase in the reliability of the SOI, increase in availability in the SOI, and increase in customer satisfaction.

The SOI consists of parts and data. Data include service-log data (maintenance records data) that constitute internal data, which are part of big data that can be provided to data analysts. Service-log data can be analyzed to identify measurable critical parameters and the most critical parts that can be used to decide which sensors to install. Data analysts include mainly researchers, in addition to the Company and partners. Sensor(s) (already installed sensors and planned to install) generate sensor data that constitute internal data. Maintenance personnel who maintain the SOI have tacit knowledge, and researchers can transform part of it into explicit knowledge in terms of visualization (information) and data that also constitute internal data.

Researchers conduct data analysis. Researchers including the main author are in process of the data analysis as part of the Company's case study. Data analysis enhances decision-making regarding the maintenance process of the SOI. Data analysis includes the following steps (nodes): data storage and retrieval, data pre-processing, data analysis, and data visualization. Decision-making regarding the maintenance process includes implementing the CBM system for the SOI (Company's request as part of the case study).

CBM implementation permits observation of anomalies that aids in detecting mechanical failure events. However, CBM passes over electronic failure events. Failure event detection and prediction allow continuous monitoring of the SOI through a dashboard using a traffic light color code. Researchers also identify the external data needed to verify the analysis results from internal data. External data is a third part data that the Company is not storing internally at their databases. Internal data is the data that the Company owns and is available to be downloaded. Implementing the CBM system requires external data. CBM generates sensor and stream data.

External data and internal data constitute big data. Big data can be provided, as mentioned, to data analysts who conduct data analysis. Data analysis investigates patterns and trends. It also supports the decision-making of the SOI maintenance process, including CBM implementation.

A CBM system can have system failures. These failures include data anomalies and downtime (CBM downtime). CBM can also give a false positive and a false negative. System failures and false alarms decrease business viability.

F. *Possible Leverage Points*

Applying systems thinking and its analysis tools aids in communicating and sharing understanding of the case study definition. This communication occurs through visualization of the systemigram. We developed the systemigram through several iterations after applying other systems thinking tools. These tools are the foundation of the systemigram development and include stakeholder analysis, a context diagram, and CATWEO analysis.

The systemigram visualizes the case study, including its multiple-unit analysis. This visualization aids in defining the case study well and sharing mutual understanding of the Company's need as part of the case study definition. The systemigram also helps communicate the case study definition

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to the Company, scholars, and other partners in the complex sociotechnical research project. The Company and the researchers used the systemigram to prioritize the most significant unit analysis in the case study. For instance, we agreed that CBM system is a long-term vision to increase the SOI's reliability. The second short-term vision is data analysis to investigate the use case for developing the CBM system. This communication aided in early validation of the Company's need as part of the case study during the early phase of the research project.

Early validation contributed to the project's success. This observation results from the Company's active participation in the research project. In addition, the Company shared all the stored and needed data with the main author of this paper. Moreover, the systemigram helped explore the problem domain that define the case study and not only touching the surface of the problem. In other words, systemigram helped at dig deeper into Company's actual (real) needs, which continues this an ongoing case study.

IV. Discussion

We developed the systemigram through several iterations. These iterations resulted in several versions of the systemigram. Some of the iterations were conducted with other researchers in the H-SEIF2 research project. The researchers were also involved in some of the workshops and interviews conducted with the Company. However, we struggled to visualize the systemigram so that is readable, as it included many nodes and explanatory links. We had to perform several iterations and use various tools. The iterations include feedback as part of the validation process with the Company. This visualization represents how researchers' knowledge is chaotic and disordered, while the systemigram aims to visualize this knowledge in a nice storytelling way. Moreover, the systemigram aids in explaining all the aspects and key stakeholders' perspectives and communicating and sharing understanding of the case study definition, including its multiple-unit analysis.

One of the essential perspectives to evaluate is the profitability aspect of the Company's request (the proposed system): the CBM system from an economic perspective. This profitability includes a business plan, including the capital expenditure (CAPEX), operating expense (OPEX), and return on investment (ROI) of the proposed system. However, we made a quick iteration to develop a rough business plan. This plan is not included in this paper, as we focus on using conceptual modeling, mainly systems thinking and its tools, to validate the Company's need in an early phase as part of the case study definition. We could also evaluate it by using other conceptual models and could include the economic perspective, such as cost optimization and performance in the systemigram(s). However, including this perspective could make the systemigram unreadable.

The Company's key personnel, including Company management and department heads of service and maintenance, validated the systemigrams. The Company's feedback indicated that the systemigram aids in communicating a common understanding and includes all the aspects and perspectives of the Company's case study.

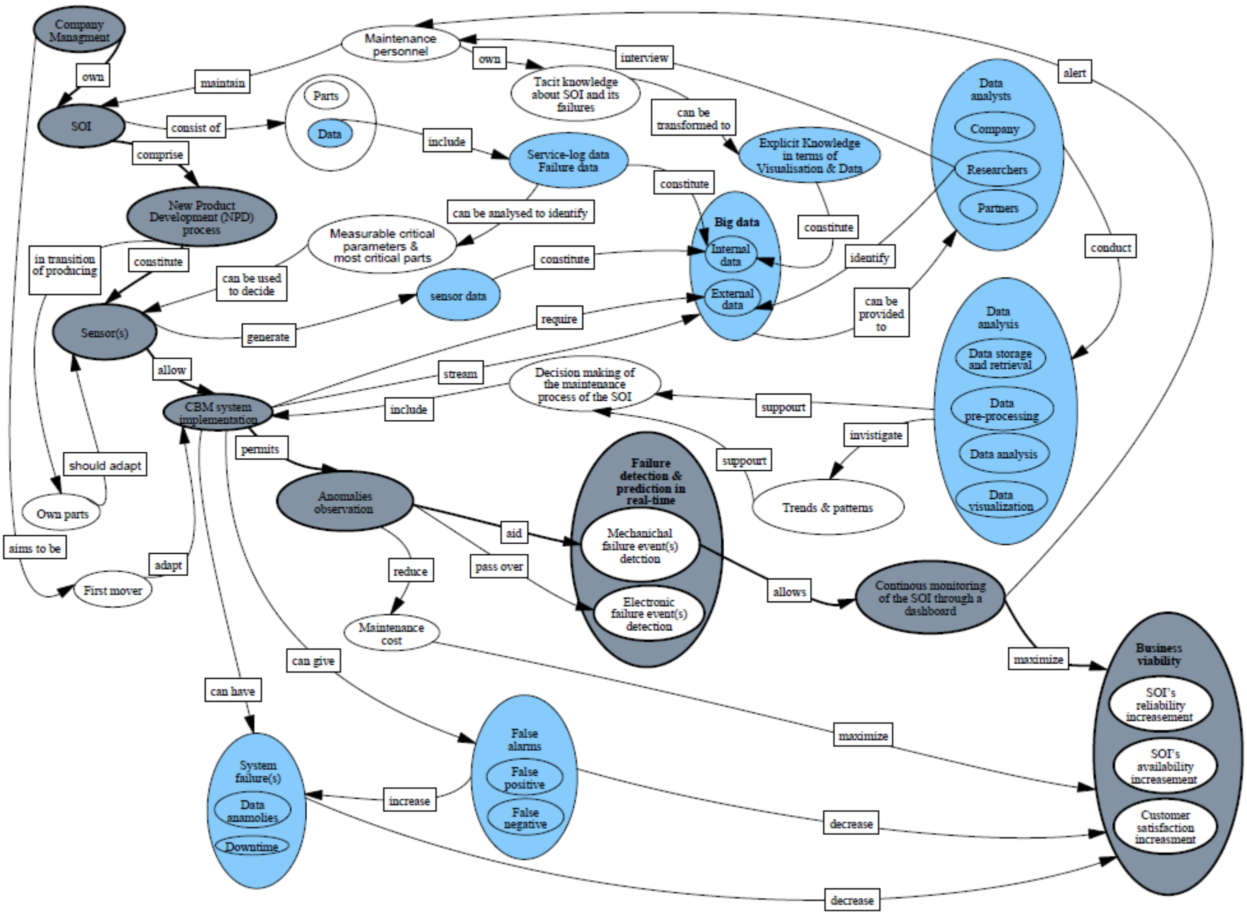

Figure 5. The systemigram visualizes the value proposition of the Company's need.

The main author tested the systemigram as a communication tool for the Company's case study with other companies in the H-SEIF2 research project. Company management also tested systemigrams as a communication tool for external stakeholders. The feedback indicated that the systemigram works as a communication tool. However, we may need to investigate further the need of other conceptual models that can be used as a supportive tool for systemigram(s). This support can be towards more concrete and specific solutions and technologies.

We could also apply other systems thinking tools to explore and increase understanding of the problem and solution domains from all perspectives and at different abstraction levels. These tools could include casual loop diagrams and conceptagon(s). We could use these tools to increase understanding of system behavior and dynamics and to organize system information and definitions. However, we believe that the systems thinking methodology and tools we applied in this paper achieved the goal of its application: early validation of the Company's case study definition.

V. Future Work

We aim to develop a financial model for the SOI. The model will investigate the profitability of implementing CBM in the short and long term. This model also aims to include the cost of the optimization and performance of adapting the Company's proposed system or request (the CBM system) as an option to increase the SOI's reliability.

Another option we plan to investigate is data analysis. We aim to analyze service-log data (maintenance record data) to increase the SOI's reliability. We believe that these data can support reliability engineering activities during the early design phase of the NPD process. In addition, we believe in using data analysis aids as input to discover the Company's actual needs. In other words, exploring the problem definition for the case study and not only touching the problem definition's surface by going forward for the Company's actual needs.

VI. Conclusion

Defining a case study well within the early phase of a complex sociotechnical research project is crucial for its success. This success can be measured by the Company's active participation and trust by sharing all needed data. We applied systems thinking and its tools to a real-industry case study. The tools include stakeholders' analysis, context diagram, CATWEO analysis, and systemigram. This application aims to validate the Company's need early as part of defining the case study well, including its several unit analyses. Feedback on the application of systems thinking methodology and its tools indicates that systems thinking aids in communicating and sharing understanding of all aspects and critical stakeholders' perspectives within the case study. This early validation helps researchers (academia) and Company (industry) investigate the Company's need and what triggers such a need to further explore the actual needs of the Company's case study.

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