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Systems Thinking Design in Action - A Duplicated Novel Approach to Define Case Studies

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Abstract

This study uses systems thinking as a duplicated research methodology to define and validate a case study early. This case study is a part of a complex sociotechnical research project. We use a systemigram to visualize the case study, including its different aspects, also called embedded units of analysis. This visualization aids in sharing, understanding, and stimulating discussion, explanation, and communication among heterogeneous stakeholders from industry and academia. We support the systemigram as a conceptual model with other systems thinking tools, including a context diagram, and Customers, Actors, Transformation, Worldview, Owner, and Environment (CATWOE) analysis. In addition, we applied other tools, such as workflow analysis and stakeholder analysis. We found that using systems thinking and its tools, mainly systemigram, aids researchers in well-defining, understanding, validating, and communicating the case study, its context, its aspects, its goals, and its relations among the heterogeneous stakeholders.

Keywords: Case study; systems thinking; systemigram; early validation; complex; sociotechnical research; methods; methodology.

1. Introduction

Case study research has three main steps (1) define the case study well, (2) select case study design, and (3) use the theory in design work [1]. This study focuses on the first step, i.e., defining and early validating the case study . This study is duplicating another case study. In the other case study, we also applied systems thinking and its tools to early define and validate a case study[2]. This duplication is part of the PhD research methodology, where we aim to develop a generic process, methodology, or tool for case studies by duplicating the research methodology[3]. Well-defined and

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early validation of a case study are vital to explore the company's needs and opportunities, especially in a complex sociotechnical research project with many partners. This definition aids in communicating the case study and its aspects among the research project's partners in the research project and inside the company of research itself. This communication is essential as the research project also functions as a sharing arena among its partners. In addition, defining and early validating the case study increases the research project's success. This success contributes to active participation, motivation, and sharing of data. Sauser et al.[4] also used soft systems methodology to develop a systemigram to define a problem, including different aspects or perspectives. Furthermore, Sauser et al.[4] claim that using systems thinking and its tools, mainly systemigram, aids in understanding the problem, its aspects, and how these aspects affect each other in a whole.

Through a co-creation session, we developed a systemigram to visualize the case study and its aspects. This co-creation session included heterogeneous participants from industry and academia. Industry and academia have different perspectives and interests. The industry is more interested in exploring how and making it work in economic constraints, while academia is more interested in exploring what and why and conducting research [5]. The systemigram as a conceptual model aids in shared understanding, stimulating discussion, explanation, and communication through visualization. We support the systemigram with other systems thinking tools. These tools include context diagram, and Customers, Actors, Transformation, Worldview, Owner, and Environment (CATWOE) analysis. In addition, we used other tools, such as workflow and stakeholder analysis. Muller recommends using, among others, iterations, time boxing, and early quantification for developing conceptual models and tools[6]. Other authors claimed to use these recommendations during their case study research [7].

We used these recommendations: iterations, time boxing, and early quantification in developing the systemigram and other tools in this study. We used failure data analysis for early quantification. The early quantification requires some simplification and assumptions. These assumptions and simplifications facilitate an early indication of the extent of the issues the researchers are interested in, such as the system's performance. In this study, we calculated the actual Mean Time between Failures (MTBF) to have an indication the system's reliability in operation. This indication and other measurements, such as calculating different failure frequencies and distributions based on different time scopes, support the researchers' understanding of the case study and its aspects. The time boxing and iterations can vary from minutes to weeks.

The research question for this study is:

"How can researchers define, understand, validate, and communicate a case study, its context, and its goals early among heterogeneous stakeholders, focusing on the company's principal and researchers involved in a case study?"

In this context, the heterogeneous stakeholders are the company's principal and researchers involved in the case study. The company's principal is the contact person who requests the Company's case study in the form of a problem statement, need, or opportunity within the research project.

1.1. Introduction to the company of interest and research project where research occurs

The company of research for this study is the largest operator of public transportation in Norway, measured by the number of journeys. In 2021, the company delivered 156 million single public transport journeys in Oslo. We call the operator the "Company-of-Interest (COI)." The COI has several subsidiaries for each public transportation . This case study addresses the subsidiary of the Oslo Metro maintenance department. We refer to this department as the "Department-of-Interest (DOI)." The maintenance department maintains the Oslo Metro, which we refer to as "System-of-Interest (SOI)."

The DOI is a partner in a research project called H-SEIF 2. H-SEIF 2 is the second iteration of H-SEIF, standing for "Human Systems-Engineering Innovation Framework." The research project aims to support more early data-driven decisions in the early-phase product development process. Most companies have a tremendous amount of data available. Using suitable models, approaches, structures, and analysis, Norwegian companies can use (big) data to achieve a competitive advantage internationally. This research project is an ongoing project investigating how high-tech complex systems companies may utilize (big) data and digitalization for innovation and effectively enhance the product development process.

2. Research Method

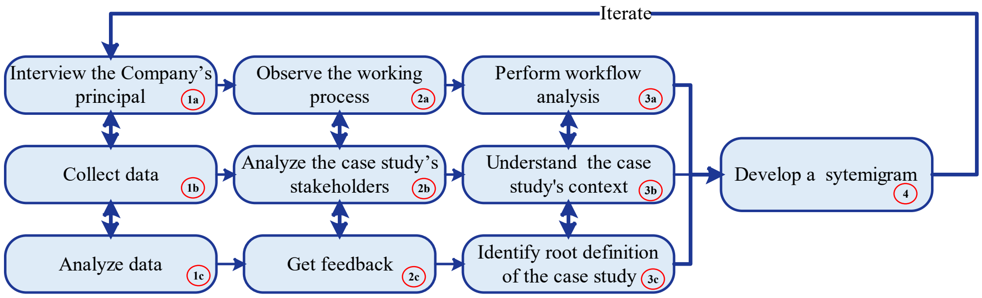

Fig. 1. The case study's methodology.

Fig. 1 shows the study's research methodology and steps. Despite a few changes and different names, these steps concur with the research methodology of the first case study, where we conduct Soft Systems Methodology (SSM)[2,8]. SSM is an iterative process aiming to define a problem to understand motivations, perspectives, interactions, and relations within the problem's aspects. SSM mainly addresses the qualitative dimension of a problem situation[4]. In the first case study, which duplicates this study, we illustrate the SSM's process and its steps in detail [2]. However, we add data collection and analysis to this study's methodology.

Moreover, we conduct these steps iteratively and recursively. We also performed some of the steps parallel to each other, as we visualize in Fig. 1. The research methodology includes the following steps:

- Step 1a: Interview the Company's or DOI's principal. In this step, we listen and ask to explore the DOI's current problem situation (case study). We also ask questions regarding stored data, focusing on feedback data, such as failure data. In addition, we investigate when it is possible to visit and observe the DOI's working process and SOI.
- Step 1b: Collect data. In this step, we collect data from the DOI provided by the principal. We collect the available stored feedback data. In this context, we collected failure data, also called maintenance record data.
- Step 1c: Analyze data. In this step, we perform the first failure data analysis looking for frequencies and different time scopes and investigating patterns. The first iterations of data analysis supported us as researchers in understanding the case study and its aspects.
- Step 2a: Observe the working process. In this step, we visited the company or DOI to observe the maintenance working process. In addition, we conducted workshops and interviews to investigate and explore the working process. We performed at least three workshops with several key persons in the DOI. These key persons included engineers, operational managers, data analysts, DOI's principal, technicians, maintenance personnel managers, etc. Moreover, we conducted informal interviews with key DOI persons during and after the visit.
- Step 2b: Analyze the case study's stakeholders. In this step, we develop a stakeholder interest map to analyze the case study's stakeholders, investigate their connection to the SOI, and list their interests.
- Step 2c: Get feedback. In this step, we present the data analysis results to the subject-matter experts from industry and academia, focusing on DOI's principals and scholars to get feedback. This feedback generates more questions, and we iterate and collect more data to answer those questions by conducting more iterations of the data analysis. The additional data collection occurred using the DOI's principal and other key persons from the DOI. The data collection included other data sources than only failure data, such as kilometer data and weather data.
- Step 3a: Perform workflow analysis. In this step, we developed a maintenance workflow. We developed two workflows for each type of maintenance the DOI performs, i.e., preventive, and corrective maintenance. However, these maintenance workflows are still a work in progress.
- Step 3b: Understand the case study's context. In this step, we aim to illustrate SOI and develop a case study's context diagram. In addition, we developed a passenger workflow to understand the interaction between the SOI

and passengers, illustrating which functions each performs. In other words, the passenger's workflow aided in achieving a shared understanding of this workflow across various DOI stakeholders.

- Step 3c: Identify the root definition of the case study. In this step, we conduct CATWOE analysis, focusing on the case study's customers from the researchers' perspective. In this context, the COI's company management is the case study's customer. The primary input for the CATWOE analysis is scholars and other researchers involved in the research project. However, the DOI's principal also validated this input.
- Step 8: Develop a systemigram. In this step, we conduct a co-creation session (workshop) with the DOI's principal and researchers involved in the case study to develop the systemigram. The systemigram aims to visualize the case study's aspects, also called embedded units of analysis, and their relations with each other. The value is not just in making the systemigram. It is also used in the discussion, explanation, and visualization of details related to the case study and its aspects during the systemigram co-development. In this context, we conducted the workshop digitally using Microsoft Teams and a shared a virtual board called Miro. All participants had access to the board. The virtual board allowed us to use digital A3s and post-its to visualize and document these details. These visualizations also aided communication and shared understanding among the heterogeneous stakeholders participating in the co-creation session (workshop) by showing and pointing at the facts. In this context, the heterogeneous stakeholders are DOI's principal and researchers involved in the case study.

We used iterations, time boxing, and early quantification when we conducted the research methodology and its steps. The time boxing varies from minutes to weeks. We used iterations to run the longer time boxing. We also performed some early quantification and measurements using the failure data analysis. The early quantification included simplifications and assumptions to indicate some of the SOI's performance early, such as MTBF, to indicate the system's reliability during the operation (maintenance) phase.

3. Applying Systems Thinking to A Case Study

This section demonstrates the implementation of systems thinking and its tools. The section starts illustrating the case study context. The section continues with stakeholder analysis by developing a stakeholder interest map. Moreover, the section shows the implementation of CATWOE analysis. Furthermore, the section shows the systemigram based on implementing the former systems thinking and other tools, i.e., context diagram, stakeholder analysis, and CATWOE analysis.

3.1. Case Study Context

This subsection aims at illustrating the case study context. The subsection starts by demonstrating the SOI, which is Oslo Metro, also called T-bane. Furthermore, the subsection shows a context diagram, also called an openness diagram.

3.1.1. System-of-Interest (SOI)

Fig. 2 depicts the SOI, which is Oslo metro [9] on the left and its map on the right[9,10]. The photos show the metro, its

Fig. 2. System-of-Interest (SOI): Oslo Metro (left) and its map(right) [9,10].

doors, platform, monitors, chairs, and hallways. Fig. 2 also shows the map for the Oslo metro. The map illustrates the metro's lines and stations. The metros drive on six lines, pass through the city's center, and stop in around 100 stations. The length of these lines in total is around 85 km. Metros operate from 05:30 (some stations start at 06:00) AM to 00:30 AM. After that, all metros park at the maintenance workshop for daily maintenance and cleaning before they go back into operation. Metros drive with a frequency of 10 minutes daily and 30 minutes after 21:00 [10].

3.1.2. Context diagram

Fig. 3 visualizes the context diagram, also called the openness diagram. Gharajedaghis[11] describes the openness principle as "*neither a problem nor a solution can be entertained free of context*." The context diagram categorizes variables into three categories: variables we can control, influence, and appreciate. For this case study, we have the following:

Controllable variables: For this study, we have the SOI, which is the metro we can or need to control to achieve the desired outcome.

Influencing variables: The variables that we can influence and are uncontrollable for this case study are the administrator and public transportation planner, the operator of public transportation, operators' company management, which includes decision-makers, operators' maintenance personnel, end-users (passengers), suppliers,

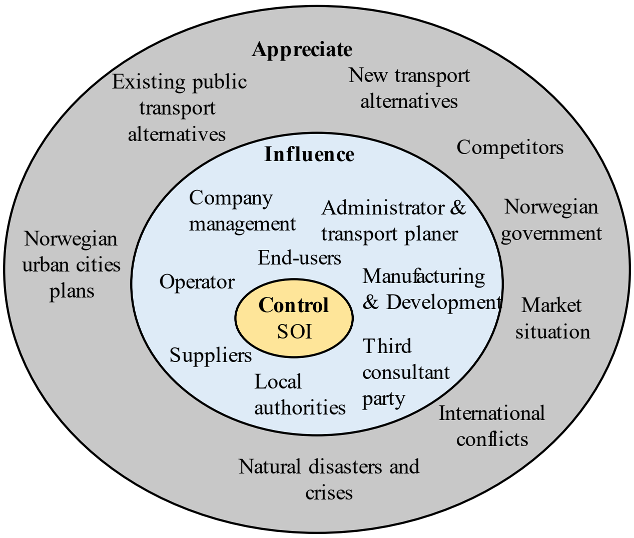

Fig. 3. Context diagram.

the third consultant party that cooperates or delivers services or both to the operator, local authorities, i.e., municipality and province, as they own the public transportation, and manufacturing and development of the metros. This study focuses on the maintenance department of the operator company. The customer for the operator company is the administrator and public transportation planner. The administrator and public transportation planner order the number of metros needed for their planned routes from the operator company.

Appreciating variables: These variables are that we cannot control or influence; thus, we need to appreciate them. The appreciating variables for this case study are new transport alternatives, existing public transport alternatives, competitors, the Norwegian urban city plan that can affect the metro's infrastructure, the Norwegian government, including railway authorities, the market situation, international conflicts such as wars, and natural disasters and crises such as the covid-19 pandemic crisis that obligated the metros to open automatically in approximately two years to avoid infections. In this context, we refer to the existing public transport alternatives as all public transport owned by the Norwegian local authorities, i.e., municipality and province. Competitors refer to all other than the ones owned by the Norwegian government.

3.2. Stakeholder Analysis

Fig. 4 depicts a stakeholder interest map for the case study. These stakeholders connect to the SOI in the middle with two types of connections, strong and weak connections. The solid arrow represents the strong connection, while the dashed arrow represents the weak connection. Fig. 4 visualizes the stakeholders into three categories: administrative, customer, and support. Each category has its specific color, as the legend portrays. Some of the stakeholders belong to two categories. Fig. 4 visualizes these stakeholders through the two colors for their categories. For instance, politicians, media, existing alternative public transportation, and competitors simultaneously belong to the administrative and support category. On the other hand, the community simultaneously belongs to the support and

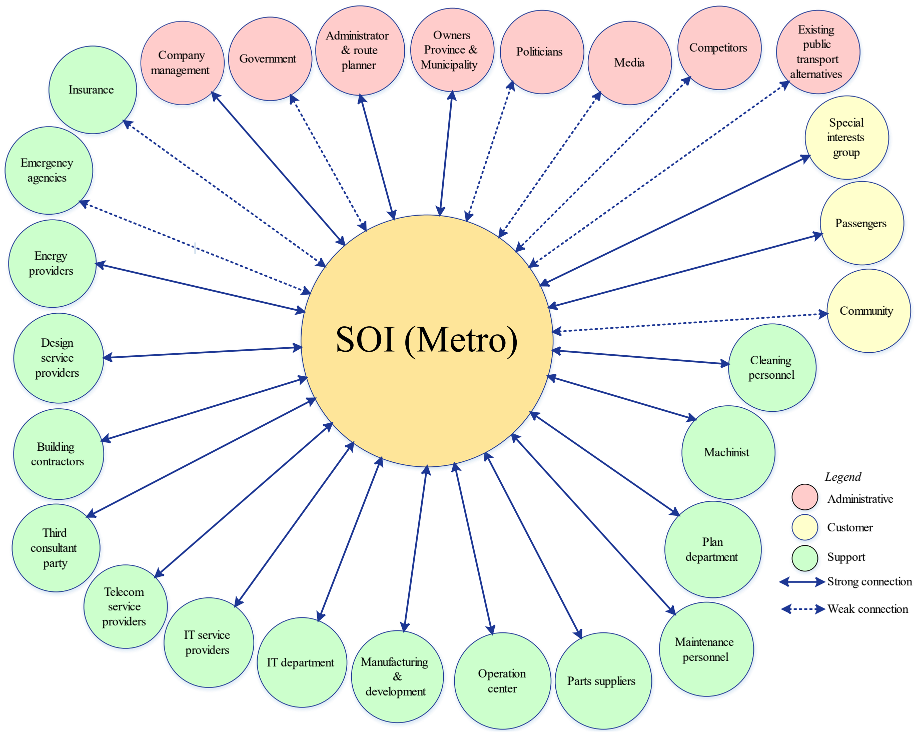

Fig. 4. Stakeholder interests map.

customer categories. Community, in this context, refers to people that are not passengers or not using the metro very often.

Appendix A lists Table 2 showing the stakeholders (who), an elaboration of these stakeholders (what), and their interests (why).

3.3. CATWOE ANALYSIS

SSM is often using CATWOE analysis. This tool aids in analyzing and defining the root definition of the problem of case study[12,13]. Checkland[12,14] defines the six elements of the CATWOE analysis as follows:

- Customers: "beneficiaries or victims affected by the system's activities."
- Actors: "agents who carry out, or cause to be carried out, the main activities of the system, especially its main transformation."
- Transformation process: "the means by which defined inputs are transformed into defined output."
- Weltanschauung or Worldview: "an outlook, framework, or image that makes this particular root definition meaningful."
- Ownership of the system: "some agency having a prime concern for the system and the ultimate power to cause the system to cease to exist."
- Environmental constraints: "features of the systems environments and/or wider systems which it has to take as 'given.'"

As the introduction mentions, this case study has the operators' maintenance department as the DOI. Thus, as researchers, we consider the operator's company management as the customer in the CATWOE analysis. Table 1 shows the implementation of the CATWOE analysis for this case study. The output from implementing CATWEO analysis is included in the systemigram, including the perspectives (actors) aspects, focusing on maintenance personnel and their department.

Table 1. The Case Study CATWOE Analysis

Aspect	Description
Customers	Company management
Actors	Administrator and route planner, Municipality, and province, Machinists (metro drivers), maintenance personnel, community, passengers, and special interest groups.
Transformation	Increase metros' availability, reliability, sustainability in utilizing materials' lifetime, and digitalization.
Worldwide	Decrease maintenance cost and time, increase maintenance quality and digitalization.
Owner	Municipality and province.
Environment	Urban city (Oslo) with it is an environment including weather (climate), inhabitants, infrastructure, etc.

3.4. Systemigram

A systemigram, also called a systematic diagram, which is a conceptual model that consists of nodes and links in the form of storytelling. The nodes are nouns, and links include verbs that connect these nodes. A systemigram starts from the upper left and ends in the bottom right. A systemigram has a mainstay, which is the central message of the story, and it is usually diagonal. Sauser et al.[4] used the systemigram to define a problem and enhance the communication, understanding, and decision of the problem of the case study and its aspects. Fig. 5 visualizes the systemigram that shows the case study definition and its aspects. The two major case study aspects are the data and human aspects. These two aspects have a light blue and orange color, respectively. The systemigram has other colors portraying the different aspects or parts in the case study. These parts include the third consultant part, the IT department, and the maintenance department. The common or overlapping aspects where more than one part

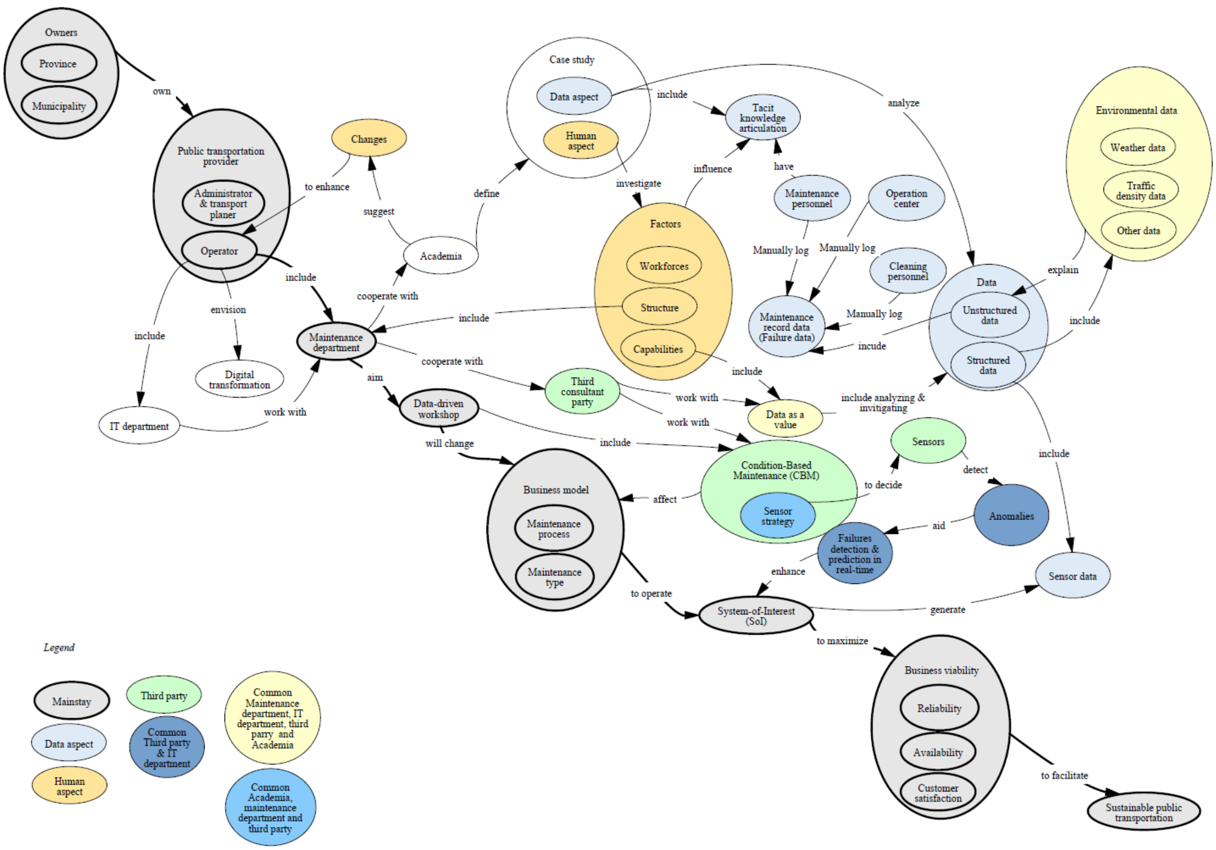

Fig. 5. Systemigram visualizing the case study and its aspects.

cooperates or shares responsibilities have other colors. Fig. 5 describes these colors in the legend. The legend also includes a grey color for the mainstay. We can read the mainstay as follows:

"*Government that includes the province and municipality owns the public transportation provider. The public transportation provider includes a public transportation administrator and planner, and operator. The operator includes a maintenance department and an IT department. The maintenance department aims at a data-driven workshop that will change the business model, including the maintenance process and types that operate the SOI (metro) to maximize the business viability to facilitate sustainable public transportation".* Business viability includes three other nodes: reliability, availability, and customer satisfaction. In other words, business viability refers to maximizing these three mentioned words.

The maintenance department cooperates with the academia, where academia aims at defining a case study. This case study includes two aspects, also called embedded units of analysis: data analysis and human factors. The human factor aspect investigates the following factors: workforce, structure, and capabilities. Capabilities include use of data as a value aspect. The data aspect includes tacit knowledge articulation in terms of data, and visualization. In addition, the data aspect includes analyzing data. These data include structured and unstructured data. The unstructured data include maintenance record data, also called failure data. The data analysis focuses on analyzing failure data.

Maintenance personnel manually log failure data and have tacit knowledge about the SOI and its maintenance process. In addition, the operation center and cleaning personnel manually log failures. The operation center receives failures directly from the metro's drivers through calls or radio communication. The cleaning personnel report any failures during the cleaning before making the metros ready for operation again.

The data aspect also includes investigating and analyzing the environmental data that can form an explanation of the failure data. These environmental data include weather, traffic density, and other data. Identifying, collecting, and analyzing environmental data is a shared responsibility or an overlapping aspect between the maintenance department, IT department, the third party, and academia. In addition, the data aspect seeks to use conceptual modeling to guide the data analysis process. On the other hand, the data aspect investigates using data analysis results to support conceptual modeling. In other words, the data aspect includes using conceptual modeling and data analysis to support and guide each other in an iterative and recursive manner.

The maintenance department also cooperates with a third consultant who explores the data as a value aspect. In addition, the third party explores Condition-Based Maintenance (CBM) that affects the maintenance business model. CBM needs a sensor strategy to decide which sensors to install. These sensors detect anomalies that aid failure detection and prediction in real-time. This detection and prediction enhance the SOI. The strategy is an overlapping aspect between the third party, academia, and the maintenance department. The IT department, as a part of the operator, works with the maintenance department as they are under the same organization. The maintenance department also cooperates with academia. Academia aims to suggest changes to enhance the maintenance department as part of the operator organization, based on the data and human factors aspects.

4. Discussion

This section discusses the results regarding the study's research question, limitations, and further studies. The study's research question is *"How can researchers define, understand, validate, and communicate a case study, its context, and its goals early among heterogeneous stakeholders, focusing on the company's principal and researchers involved in a case study?"*

Early validating, defining, understanding, and communicating the case study, its context, and its goals are vital for researchers to move in the right direction effectively. This latter is more crucial when the researchers are PhD research fellows with limited time and resources in terms of funding to complete their research. In addition, it is essential if the case study is part of a complex sociotechnical research project as it aids in project success. We can measure this success through the company's active participation, motivation, and sharing of needed data for the research.

In this study, we apply systems thinking and its tools, mainly systemigram, to visualize and communicate the case study and its embedded units of analysis, also called aspects among heterogeneous stakeholders. In this context, the heterogeneous stakeholders are the company's principal and researchers involved in the case study. The visualization and communication aid in increasing researchers' understanding and early validating of the case study, its context, goals, and aspects. This understanding aids in defining the case study well, which is the first step in case study research. We developed the systemigram in a co-creation session (workshop) with the researchers involved in the case study and the company's principal. We used A3s and post-its as well during the co-creation session using a virtual shared board. We found that the systemigram is valuable, especially in making the main story, i.e., the mainstay to explore the case study's current situation, goals, possible aspects to achieve these goals, and the relations among these aspects.

We also observed that co-creating the systemigram through a workshop stimulates discussion and explanation of the case study, its aspects, and how they relate to each other. These discussions and explanations allow the company's principal and researchers to express their perspectives, expectations, pain points, and prioritization of the study's aspects. Using A3s and post-its enhanced the shared understanding and communication of the details and study's aspects through visualization. Visualization in terms of post-its allowed us to move and point out these details and aspects. Thus, we emphasize the value of the co-creation session. Moreover, we emphasize the importance of making the systemigram that stimulates these discussions and explanations among the participants.

We used other systems thinking tools to support the systemigram. These tools include context diagram and CATWOE analysis. In addition, we illustrated the SOI and performed stakeholder and workflow analysis. The workflow analysis investigates the maintenance working process, including preventive and corrective maintenance. In addition, we developed a passenger workflow to understand the interaction between the SOI and passengers, illustrating which functions each performs. Workflow analysis aided in achieving a shared understanding of the workflow across the DOI's stakeholders. Implementing the systems thinking tools and other tools enhanced the researchers' understanding of the case study and its context. This implementation also improved the systemigram development. We shared the results of implementing these tools with the company's principal and researchers involved in the case study. We also co-created some of these diagrams, such as workflow and stakeholder analysis. The co-creation sessions of these tools strengthened the communication and shared understanding of the case study, its context, and its aspects among the company's principal and researchers involved in the case study. However, we need to investigate further the effectiveness of the systemigram during the co-creation session with other researchers for observing the participant's involvement other than our observation as researchers facilitated and observed this co-creation (workshop) session. Facilitating and observing may cause biases and losing some observations because of having two roles simultaneously.

We used iterations, time boxing, and early quantification. We used failure data analysis for early quantification. The early quantification included assumptions and simplifications to indicate essential measurements, such as determining the Mean Time between Failures (MTBF) to measure the SOI's reliability. One of the simplifications and assumptions we made to calculate the MTBF is that the failure rate is constant. Furthermore, the failure data analysis investigated the frequencies, distributions, and correlations of SOI's failures based on different time scopes.

In addition, we received feedback from subject matter experts from industry and academia. These experts included mainly researchers involved in the case study and the company's principal. This feedback generated more questions, and we attempted to answer them by collecting other data sources and iterating with the data analysis. We are including other company experts in the ongoing research to get feedback on the data analysis. We also need to investigate other ways than collecting and analyzing failure data for early quantification such as co-creation workshops. Furthermore, we are conducting a more comprehensive stakeholder analysis, focusing on the Company's employees and their relationship with the maintenance processes and software systems they use in these processes.

5. Conclusions

This study investigates applying systems thinking and its tools to enhance researchers understanding of the problem definition of a case study, its context, aspects, goals, and how these aspects relate to each other in a whole to achieve the case study's goal(s). In this context, we illustrate the SOI and its parts. Furthermore, we applied the following tools: workflow analysis, stakeholder analysis, context diagram, and CATWOE analysis. We also developed a systemigram visualizing the case study and its aspect, where we support the systemigram with the output of implementing the mentioned tools.

We found that applying systems thinking and its tools, mainly systemigram, in a co-creation session (workshop), stimulated discussion and explanation of the case study's aspects and details among heterogeneous stakeholders. These heterogeneous stakeholders are mainly the company's principal and researchers involved in the case study. We used A3s and post-its during the workshop using a shared virtual board. The feedback is that using A3s and post-its enhances the communication and shared understanding among the workshop's participants through visualization. This visualization allowed the participants to move and point out the details related to the case study's aspects. In other words, the value is not the only the output of the systemigram as a figure or a conceptual model. The value is also in the interaction and co-creation process of developing systems thinking tools (conceptual models), mainly systemigram. This interaction stimulated discussion, explanation, and visualization of the case study's aspects and details using post-its. However, making a systemigram assisted in visualizing the big picture of the case study's current situation, its aspects, goals, and relations among the aspects to achieve the study's goal(s). This visualization aids researchers in communicating, well defining, understanding, and validating the case study, its context, and its aspects and goals early among the heterogeneous stakeholders.

Moreover, we collected and analyzed the feedback data in terms of failure data. We analyzed the data to investigate frequencies, distributions, and correlations based on different time scopes. We also collected environmental data and other data sources to form an explanation and explore patterns and correlations for the failures. We shared the data analysis with subject-matter experts from industry and academia. The experts included mainly researchers involved in the case study and the company's principal. We plan to collect feedback from other experts inside the company and academia. The data analysis is still a work in progress. However, we used the data analysis as an early quantification to have an indication about the system's performance, such as calculating the actual MTBF to indicate the system's reliability. This indication gives the researchers valuable information to explore the actual need behind the company's case study (request) such developing a CBM system for their SOI. For instance, if the MTBF is in hours, then the actual or urgent need is to increase the system's reliability by increasing the design robustness. On the other hand, if the MTBF is in weeks, then the actual need for the CBM plan would be a parallel plan together with increasing the system's reliability. In case the MTBF is in months or in years, then, the actual need behind the CBM would be a more strategic decision towards a digital twin to be a more effective, and data-driven company in the digital transformation way aiming to be more effective in operating their processes.

Early quantification is one of the recommendations, together with iteration and time boxing that we used to conduct the study's research methodology steps and to develop the systemigram as a conceptual model and its supporting tools (models). We also plan to investigate other ways than collecting and analyzing data for early quantification. This investigation includes early quantification using visualization to articulate tacit knowledge or workshops with the company's key persons.

Further research includes the continuation of exemplifying the use of conceptual models and data analysis to guide and support each other in an iterative and recursive manner. We are continuing collecting and analyzing internal and external data. Internal data include failure data from operation (maintenance), whereas external data consist of environmental data, mainly weather data. Moreover, we are developing more and other conceptual models such as workflow analysis of maintenance processes, value network, functional flow, timeline, key drivers, fitness-for-purpose, and so forth. We continue using the following recommendations: iterations, early quantification, and time boxing in data analysis and conceptual modeling. In addition we are using other recommendations such as continuous feedback from the subject-matter experts and conducting multi-view perspectives.

Acknowledgments

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Appendix A. Stakeholders, an elaboration of these stakeholders and their interests.

This Appendix lists Table 1. Table 1 illustrates the stakeholders (who), an elaboration of these stakeholders (what), and their interests (who).

Table 2. Stakeholders, an elaboration of these stakeholders and their interests.

Stakeholders (who)	Elaboration of stakeholders (what)	Interests (Why)
Company management	Operator's company management. The management includes maintenance workshop director, Chief Executive Officer (CEO), etc.	Availability, reliability, maintainability in terms of cost and time, maintenance quality, sustainability in utilizing materials' lifetime, and digitalization.
Administrator and route planner	The administrator and route planner order transportation from the operator.	Profit, Operating Expense (OPEX) and Capital Expenditure (CAPEX), passenger satisfaction, and first mover to technology.
Owners	Municipality and province own the public transportation, including metro	Economy regarding cost and profit of providing public transportation as a service, and public including passengers and community satisfaction.
Government	Regulators and surveillance organs, including railway authorities.	Public transportation, including the metro, follows regulations and standards to ensure safety.

Politicians	Politicians in the municipality, region, province, national politicians representing political parties.	Economic shareability, public transportation accessibility, and public satisfaction.
Media	All written, seen, and heard media.	Monitoring the public transportation provider and operator due to their delivered services, its cost, public satisfaction, contracts, services availability and following regulations in their processes.
Existing public transport alternatives	All public transportation is owned by the Norwegian government including municipality and province.	Availability, reliability, sustainability, and digitalization.
Competitors	Any alternative transportation than the ones owned by the Norwegian government.	Profit, reliability, and availability.
Passengers	All persons using the metro except the special interests group.	Availability, accuracy of scheduled routes, comfort, prices, and accessibility in terms of the network access points and inside the metro.
Special interests group	Persons using the metro and having special needs.	Availability, reliability, accessibility, and safety of using the metro are due to their needs.
Community	People living around the metro do not use it so often or do not use it at all.	Level of metros' operational noise, comfort, accessibility to their estates, and not affecting their day-to-day life.
Machinist	Metro's drivers.	Safety, availability, accuracy of metros' scheduled routes, and accessibility to the metro on planned drive routes.
Operation center	The operation center is part of the metro's operator company. The machinist reports the failure directly to the operational center. The operation center also assists in high-severity failures.	Availability to aid in high-severity failures and communication with the machinist, easy two-way communication with machinists and maintenance personnel.
Plan department	The planning department is part of the metro's operator company. The plans department plan the preventive, also called planned maintenance, based on the manufacturer's instructions.	Accessibility and overview of the maintenance plan and needed parts, easy to notify and communicate internally focusing on the maintenance department and warehouse.
Maintenance personnel	Operator's personnel who maintain the metro, including corrective and preventive maintenance. Maintenance personnel includes operational maintenance workforce, foreman, maintenance signal controller, etc.	Availability, reliability, repairability, and safety for passengers and for conducting maintenance tasks.
Cleaning personnel	Operator's personnel who clean the metro at daily and planned intervals.	Ease of work, accessibility to all metros' parts to clean, accessibility to cleaning materials and tools, safety for passengers themselves, and conducting cleaning tasks, including removing all tags inside and outside the metros.
Emergency agencies	Emergency organs include police, fire, and ambulances.	Proper emergency response in terms of response time, accessibility, and safety for metro crew, passengers, and emergency personnel
Insurance	Insurance for metros' owners and operator	Cost of accidents for operators' personnel and passengers.
Manufacturing & development.	The manufacturer and developer of the metro (SOI).	Maximize profit, getting feedback data to improve their products and services.
IT service providers	Information technology service providers provide the metro's operator company with several software systems and databases.	Maximize profit, getting feedback data to improve their products and services.
IT department	IT department is a part of the metro's operator company. IT department also provides IT services to other departments, such as the maintenance department.	Availability and accessibility to provide IT services, data, and IT help to the metro's operator companies, including their departments.

Telecom service provider	Telecommunications service providers supply communication between metros and two ways of communication between the meteors' operators and the metros.	Maximize profit, getting feedback data to improve their products and services.
Third consultant party	Metros' operators cooperate with a third consultant to develop products and services, such as the Condition-Based Maintenance (CBM) system.	Maximize profit and project success.
Building contractors	Metros' operators hire building contractors to enhance or build existing or new buildings.	Maximize profit and project success.
Design service providers	Metros' operator and owners cooperate with design service providers to design metros.	Maximize profit and project success.
Energy providers	Metros' operator and owners cooperate with energy providers, including electricity suppliers to their facilities, buildings, and metros.	Operating Expense (OPEX) and Capital Expenditure (CAPEX), and maximize profit,
Part suppliers	Metros' operators have parts suppliers to maintain and clean their metros. These part suppliers can be part of the metro's manufacturer and developer.	Maximize profit, getting feedback data to improve their products and services.

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