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A Systems Thinking Approach to Data-Driven Product Development

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Abstract

The amount of information in our society and its opportunities have given rise to Big Data research. The systems supplier industry needs suitable tools and methods to ensure the harvest and utilization of Big Data in their product development. This paper used Systems Thinking to analyze the current state in the industry and suggested leverage points for further research direction. The findings suggest that the research project should emphasize the industry cases, the collaboration between the companies and academia, develop a Big Data systems architecture, and maintain a socio-technical view.

Keywords: *product development, socio-technical systems, big data analysis, systems thinking, systemigram*

1. Introduction

1.1. Human systems engineering innovation framework

There is a collaborative framework helping engineers and designers to create innovative systems called the Human Systems Engineering Innovation Framework (H-SEIF). Its second iteration focuses on harvesting value from big data, digitalization, and enabling data-supported early decisions. The H-SEIF 2 research project aims to improve the companies product development processes through applicable industry cases. Nine companies with nine industry cases from various domains and two universities are part of the research project, using an industry-as-laboratory approach.

Pretorius et al. (2019) highlights systems thinking and soft systems methodology (SSM) as methods to be considered for identify the industry requirements. Through a literature review, Salado and Nilchiani (2013) confirmed that systems thinking, and SSM in particular, be suitable for identifying socio-technical problems, behaviors and relations. Therefore, we apply a Systems Thinking approach to understand the complex industry environment and companies' needs and identify leverage points in future research. The insight from the companies defines the H-SEIF 2 research direction.

1.2. Big data in product development

The world is becoming increasingly complex due to the interconnectivity of multiple sub-systems and human involvement. Furthermore, the need for information and the availability of information is higher than ever. Today's industries, such as defense, transportation, maritime, finance, health, telecom, and space, have customers demanding new, integrated, and attractive systems. Numerous devices generate vast amounts of data, and almost every industry is compelled to harvest and utilize such data for competitive advantage (Provost and Fawcett, 2013).

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Value creation from Big Data includes customer need-identification, opportunity-recognition, product- and service-design, risk management, quality management, and generation of knowledge from data management (Urbinati et al., 2019). Müller and Jensen (2017) suggest a strong linkage between the application of Big Data and value creation that depends on technology, organizational context, and managerial action to succeed. We use the following definition of Big Data: *"Big Data is the Information asset characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value."*. De Mauro et al. (2016).
The use of Big Data in product development is a new research area. Zhan et al. (2018) explored how Big Data can be used for customer expression of unrecognized needs. Trabucchi and Buganza (2018) developed a process that used data as the trigger point for innovation and guidance for entrepreneurs and managers of complex systems. Tao et al. (2019) presented a product-design framework based on a digital-twin approach involving big-data analytics. Staack et al. (2019) took a system of systems and a global approach to tackle the complexity in aeronautical product development because of dynamic factors such as technical, economic, managerial, and regulatory disturbances.

1.3. Applying systems thinking

This section presents Systems Thinking and the tools used in this paper. Richmond (1994) introduced the term Systems Thinking, and the term has several definitions. Arnold and Wade (2015) combined systems thinking and literature review to define Systems Thinking as: *"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."*. The authors follow this definition and apply three systems thinking tools. This paper identifies the system and its boundaries through an openness diagram, understands the systems with CATWOE, predicts the behaviors by designing a Systemigram, and finds what to modify by analyzing leverage points needed to achieve the research goal.
Openness Diagram. Systems thinkers tend to see systems as open living systems, which can only be understood in the context of their environment (Gharajedaghi, 2011). Therefore, we need to identify the system and its boundaries. Additionally, we see that everything is dependent on everything else. Gharajedaghis (2011) describes this through the openness principle as *"neither a problem nor a solution can be entertained free of context."* By such a view, we can categorize into things we can control and things we cannot, and the transactional environments in between. We use three variables within the openness diagram. *Control* - The system we can control and affect. *Influence* - The systems we cannot control but influence. *Appreciate* - The systems we cannot directly control nor influence.
CATWOE (Smyth and Checkland, 1976) is a tool developed as part of the Soft System Methodology to help define the root definition and analyze the problem situation. The CATWOE mnemonic is *Customer* - the victims or beneficiaries of the transformation process. *Actors* - those who would do the transformation process. *Transformation process* - the conversion of input to output. *Weltanschauung* - the worldview that makes this transformation process meaningful in context. *Owners* - those who could stop the transformation process. *Environmental constraints* - elements outside the system which it takes as given (Smyth and Checkland, 1976).
Systemigram is a conceptual representation of a system with nodes and explanatory links that communicate behaviors. Boardman and Sauser (2008) created the tool to visualize systemic diagrams and capture systems thinking. The Systemigram is beneficial as it helps people think systematically about the system and understand the interrelations in the problems. The conceptual model can aid in identifying causal loops and leverage points for deciding where to emphasize modifications on the system to achieve the desired goal.
The research objective is to identify research directions for how the industry can utilize big data in their product development. We use a Systems Thinking approach to understand nine Norwegian high-tech companies' current state and needs. We ask two research questions (RQ). RQ1: What is the need for Big Data and digitalization in the nine industrial actors? RQ2: What leverage points should the research project focus on to fill the gap in the industry?
The paper is organized as follows. First, it presents the research method. This is followed by the Results Section with four sub-sections. It starts with summarizing the problem situation in the

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industry. Then the section defines the systems boundaries to understand the context, followed by defining and analyzing the problem situation. Further, the section visualizes the behaviors of the system through a Systemigram. The Discussion elaborates possible leverage points. Finally, there is a conclusion.

2. Research methods

This section explains the method and process used for this paper. The research method is based on the Boardman Soft Systems Methodology (BSSM) (Boardman and Sauser, 2008). It improves upon Checkland's Soft Systems Methodology (Checkland, 1999) by acknowledging that there is no one right path, being an iterative process, and revolves around participative design activities. The BSSM is a seven-step process depicted in Figure 1, bridging the real-world and systems thinking.

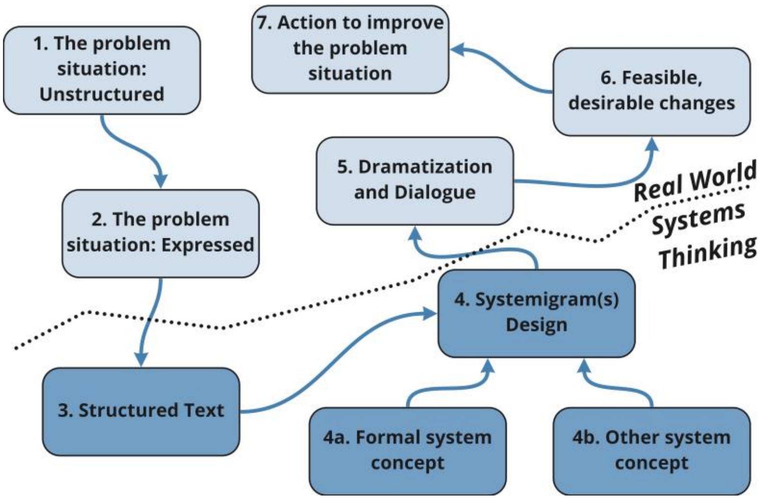

Figure 1. Boardman Soft Systems Methodology, redrawn from (Patrick Eigbe et al., 2010)

The authors performed these steps.

Step 1 - The problem situation (unstructured): In this step, the authors captured the situation expressed through meetings with each industry partner. The researchers ran interviews, followed by interactive workshops to express their main challenges and expectations. Additionally, the researchers held workshops where the industry partners collaborated.

Step 2 - The Problem Situation (expressed): Each industry case got a one-page description based on step 1. The authors performed follow-up meetings to verify that the industry partners and the researchers' understanding were aligned.

Step 3 - Structured Text: The authors moved into the systems thinking domain by conceptualizing the structured text from step 2. The goal was to find the root definition of the system by framing the system's boundaries and creating a CATWOE.

Step 4 - Systemigram Design: In this step, the authors captured the essence from the conceptual thinking based on the structured text. The authors used Systemigram as the conceptual modeling tool.

Step 5 - Dramatization and Dialog: When moving back to the real-world domain, the authors compared the model from step 4 to the problem situation described in step 2. The authors discussed, optimized and verified the conceptual model with stakeholders.

Step 6 - Feasible, Desirable Changes: The authors discussed and evaluated the proposed leverage points according to the cultural and technical feasibility.

Step 7 - Action to improve the Problem Situation: The last step was to highlight the findings to the research consortium. Future work for the research project will be to implement the suggested actions.

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3. Results

The following section of the paper presents the results and analysis of the problem situation expressed by the industry, Systems Boundaries of H-SEIF 2, CATWOE to communicate the purpose of the research project and a Systemigram visualization of the context.

3.1. The problem situation expressed

This section compiles steps 1 and 2, which were the unstructured and expressed steps of understanding the problem situation. There are nine diverse cases to study, with the intention to learn how to bring value from big data. Below are brief descriptions of the cases the companies bring into H-SEIF 2. The nine Norwegian companies range from small, medium to large in size and revenue, where some are young in the business and others have a long legacy. Additionally, there are two universities with expertise in systems engineering and architectural design. The last section expresses the value of collaborative participation.

3.1.1. Company cases

Company Alpha is a large Defence company that uses traditional development methods with high-security restrictions and unreachable operational system data. Their products have a long development time, making early validation a challenge. The industry case for Company Alpha is related to their remote weapon systems, and they will focus on the Human-Machine Interaction in Combat Systems. This system will have multiple sensors and sub-systems to be controlled by an operator working in a high-stress environment. The research focuses on finding parameters essential for the user's ability to operate the system and analyzing the user experience. For Company Alpha to improve its product development, they will use a simulator to explore and validate the product design. The research goal is to have a system where operators can make good decisions without exceeding the user's cognitive load. Additionally, give the engineers and managers an understanding and process for utilizing big data in early development.

Company Bravo is a young and small product-oriented company working on novel solutions emphasizing on autonomous tools and systems operating in industrial environments. Their industry case improves user interaction for autonomous industry machines, such as wheel loaders, that move materials between stations within a closed environment. The vehicles shall function with and without an operator driving them. An industry challenge is to get access to physical testing, as stopping the production for an extended period is undesirable. It takes time to train the system to function autonomously. The research goal is to have an incorporated method in the early phase that is fast and easy to use, to ensure a validated system. Additionally, being capable of using big data to optimize operations and user interface for operators.

Company Charlie is a large international Oil and Gas service provider with a long experience with subsea development and services. They are a large traditional systems engineering company, working in all product life cycle stages. The company has various data, information, and knowledge from a comprehensive library of assets, cumulated for decades. There has been an ongoing digitalization and modernization of the industry. Some value propositions are handling and utilizing big data and becoming a data-centric company. Their industry case is within a data-management system that is a step towards a digital twin solution. They are creating a system for data related to assets used by subsea service personnel. The users will be given information in seconds, show status, behavior, what happened, engineering info, production info, historical info, and more. The system is made by having a structure of all data sources that were not initially connected. The research focus is to make the system more user-centric and data-centric. The research goal is to give users efficient, easy, and pleasant access to connected, validated, and contextualized assets information. The service will help the users make fast and sound data-driven decisions based on automated data.

Company Delta is a medium-sized systems engineering-oriented organization operating as a consulting company focusing on product and service development. They will innovate new data-driven decision-making and co-creation services using data to increase customer satisfaction in their projects. Their industry case is to develop a Digital Twin architecture for a medical device. The

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Digital Twin will simulate accurate tumor movement from patient and machine data during treatment, creating a digital representation of the patient with a real-time body sensor system. Digital Twin for treatment improvement is a new and somewhat undefined concept, making the development challenging. The research will find methods for presenting proof of concept to achieve further funding and build confidence in the solution through early validation. The research goal is to identify good system engineering practices when developing a digital twin and using big data for data-driven decision-making.

Company Echo is a large and experienced organization that provides services within mapping, land and hydrographic surveying, cadastre, and cartography. They see that dynamic data has become more relevant in our society. Additionally, Company Echo is in a strategic digital transformation. Their industry case is creating a Digital Twin of a city, aiming to prepare and aid in flooding disasters with the help of geo-data, sensors, modeling, and simulations. The current state for industries and organizations is that only resource and knowledge-rich companies can utilize big data. The research focus on developing a method for utilization data from Company Echo, which is transferable to smaller organizations with less funds and assets. The research goal is to have a dynamic data platform that provides valuable data to advanced projects with high competencies and resources and smaller organizations using off-the-shelf software.

Company Foxtrot is a large company working at the crossroad between IT and finance, driven by entrepreneurial working methods. They create products and service packages for companies that incorporate techniques such as machine learning for accounting tasks. Their culture is based on an entrepreneurial mindset, moving fast from idea to development, failing early and agile development. Their case takes the basis in formalizing the Company Foxtrot process, developing best practices, and increasing efficiency in all development departments. The research will observe multiple projects and generate a transferable process that focuses on rapid prototyping and co-creation. A challenge is to capture the developers' tacit knowledge and find a way to transfer this knowledge over to others. The research goal is to have a transferable product development method that works in an entrepreneurial organization.

Company Golf is a large systems engineering-oriented organization which operates in the Maritime sector. The company has considerable knowledge and data from vessels and systems, hoping to extract value from these sources. They are searching to integrate better design, creativity, and data-driven decisions in the early phase of their traditional development process. Company Golf is bringing in two industry cases into the research project.

a) *Industry Case 1* is related to the use of big data in their smart remote service. This service gives the engineers access to perform remote support on the customers' vessels. The research focuses on automating the manual work performed today, such as gathering, analyzing, and presenting data, which takes much time. A challenge is that much of the data is fragmented. The research goal is to have a method for using this data in product development and installation. Additionally, to monitor, systemize, and learn how end-users use their systems.

b) *Industry Case 2* is an early exploration process; an internal method Company Golf has for discovering customer needs and problems in the early development phase. This process emphasizes the increased need to digitize fleets for better management. The process might aid in understanding what data customers have access to and what needs to be installed to increase the available data. The research goal is to optimize and validate this process.

Company Hotel is a small company that delivers installation, maintenance, and operations of automatic car park systems. They are in the transition to becoming a full system delivery company. Company Hotel wants to improve its products by including additional systems surveillance, as reliability is paramount. The industry case is about harvesting data from their parking systems to achieve condition-based monitoring and predictive maintenance. To achieve their goal, they must add additional sensors, implement infrastructure, and have a process for utilizing the data. The research focuses on developing architecture and using big data in smart parking systems. The research goal is to have a system that monitors user patterns to help develop maintenance services and user interfaces—additionally, having a method that utilizes data from maintenance services to improve product development.

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3.1.2. Value of collaboration

The participants' observation and feedback suggested that collaboration in workshop meetings between the industry partners and the researchers was valuable. During the problem situation phase, there were primarily two types of collaborations. One was the interactions between the various industry companies during project meetings. These meetings had interactive workshops after a subject matter expert talk or a presentation from one of the industry case problems, challenges, ideas, and visions. The other type of collaboration was interactive workshops and collaboration internally between the academic researchers and employees from the industry partners. Such work enhanced the participants' understanding of the research project's situation, challenges, and expectations. The academic partners saw value in having a close relation to the industry, as it gave them access to collect data and experiment theories.

3.2. Openness diagram

In the following sections, the authors conceptualize the structured text to find the root definition of the system. First, the authors frame the system boundary of H-SEIF 2 in an openness diagram to overview the stakeholders, systems, and environments. This paper uses the same definitions of relevant stakeholders in product development as Majava et al. (2015). The H-SEIF 2 research project is an open system controlled by the project management, the industry case owners, and the researchers. Figure 2 shows the project team's (*Control*) reach of *influence* and what to *appreciate*.

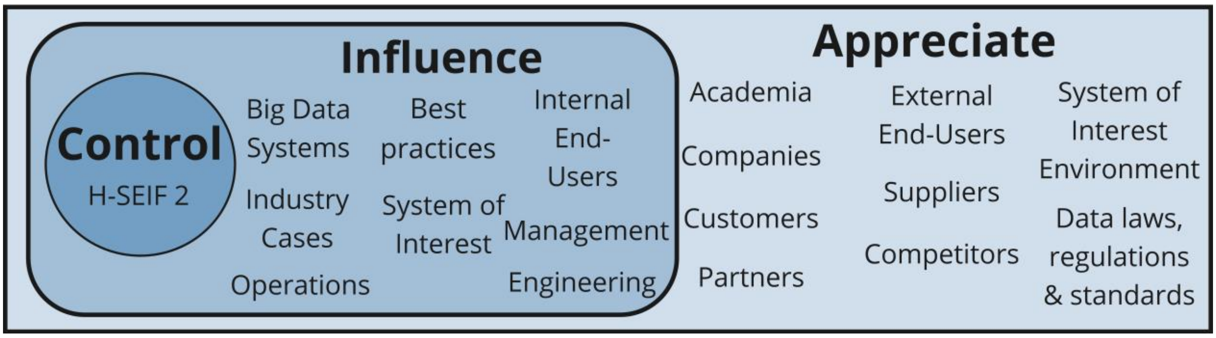

Figure 2. Openness Diagram

H-SEIF 2 project target is to *influence* the industries to use best practices with methods, processes, and tools appropriate for utilizing big data in their product development. The output from the product development process is referred to as "System of Interest" and can be products, services, and systems. For the project's duration, the industry cases will explore and verify the best practices by using them to develop their systems and users. Based on the industry cases, we have the Engineering, Management, Testing and Operations in their respected environments as influential stakeholders. Engineering is those who design and develop the system of interest. Management represents those with tactical and strategic decision-making responsibilities. Operations work in the later stages of the product life cycle, such as manufacturing and testing. The authors included the Big Data System as it is a central part of H-SEIF 2. This system includes, but is not limited to, data, sensors, infrastructure, databases, architecture, and software. End-users will use the systems of interest and are, in some cases, part of the product development. Internal end-users are employees who deliver a service, such as monitoring and maintenance.

End-users, when they are external stakeholders, we *appreciate* their contributions, such as feedback during testing and operations. However, we cannot influence their behavior. We should also note the environment the System of Interest is working in and manipulates. Customers, Partners, Suppliers, and competitors are stakeholders we categorize as *appreciate* as they have interest but are out of reach of direct influence. Additionally, we have the data laws, regulations, and standards to be aware of. The company organizations and academic institutions are within the appreciate abstraction due to the indirect contribution to market gain and human knowledge.

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3.3. CATWOE

We apply CATWOE to understand and communicate the purpose of the system, with the point of view of the initiator and beneficiary, which is the industry partners and academic researchers. The H-SEIF 2 research partners are defined as the Customer, as seen in Table 1. The partners are the industry case owners and the researchers from the universities.

Table 1. CATWOE of H-SEIF 2 Research Project

CATWOE	Values
Customer	H-SEIF 2 research partners
Actors	Engineering, Management, Operations, End-Users, Company Customers
Transformation	Big Data and Digitalization in Product Development Process for Early Validation
World View	Improved Product Development for company customers satisfaction in the high-tech market
Owner	Industry partners, academic partner institutions
Environment	Industry Cases

There are numerous *actors* on various levels of influential power and interest. The main actors are those in control of H-SEIF 2. However, the relevant *actors* on the system of interest level are the Engineering and Management who develop the systems. Additionally, the Operations and End-Users of the systems. The Company Customers are here defined as those buying the system solutions from the industry partners.

The *transformation* is connected to the H-SEIF 2 goal and the needs expressed by the industry partners. The focus can be expressed as the transformation to achieve Big Data and Digitalization in Product Development Process for Early Validation. The transformation will influence the current best practices and the Big Data Systems.

The context (*World View*) being transformed is the actors and systems associated with the product development process and the process itself, aiming to achieve higher company customer satisfaction. Additionally, the system of interest's environments will experience change.

We see the *owners* as the partner companies who are members of this project, as they invest resources to their employees to complete the work in the H-SEIF 2 research project. If they do not see the value of contributing, they can pull out of the agreement. We also have the academic organization as co-owner due to financial assistance from the research grant. Academia expects research contribution through publications of research findings.

The *environment* is the industry cases used to understand, explore, optimize, and verify each respected research focus. The industry cases have their own unique best practices, systems, and environments in which they operate in.

3.4. Systemigram

The authors use a conceptual representation to communicate a story about the system under investigation. Figure 3 shows the Systemigram of the H-SEIF 2 research project. The Systemigram gives us insight into the main stakeholders, systems and environments perspectives, and connections to the research project. Mainstay, also known as mainstream, is the purpose of the system and is highlighted in the thicker red arrows. The mainstay story reads: *H-SEIF 2 consists of industry partners who collaborate and share best practices used in product development processes that are verified and validated in industry cases which has access to Big Data systems used with tools and methods to perform early exploration and validation to design suitable systems of interest to deliver higher satisfaction to company customers.*

The Systemigram has a dashed line, dividing Figure 3 into two main parts. We have the "Industry and Academia Research" on the left side and the "Data-driven Product Development" on the right. The two parts are connected and need of each other for the research project.

The "*Industry and Academia Research*"-part shows the collaboration between the industry partners and academia. The academic researchers support the industry by suggesting best practices and processes based on the current body of knowledge and industry practices. Additionally, they aid the

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industry by verifying and validating the suggested methods in suitable industry cases. The findings will benefit academia through publications and insight into relevant industry environments. This collaborative loop is suitable for an industry-as-laboratory research approach.

The "*Data-driven Product Development*"-part shows the focus domain for the research project. The engineers, managers and operators are the ones who contribute to the design of Big Data Systems, primarily based on their need for information from the System of Interest and the end-users. The Big Data Systems must be used with tools and methods before transforming data into information and knowledge. The engineers, managers, and operators can perform data-driven decision-making with the needed information and knowledge. The insight might improve the capabilities of early exploration and validation. At the same time, co-creation can further improve the understanding of the system. Therefore, we presume that data-centric information and knowledge, together with co-creation, will improve the early phase of systems development, ultimately enriching the customer.

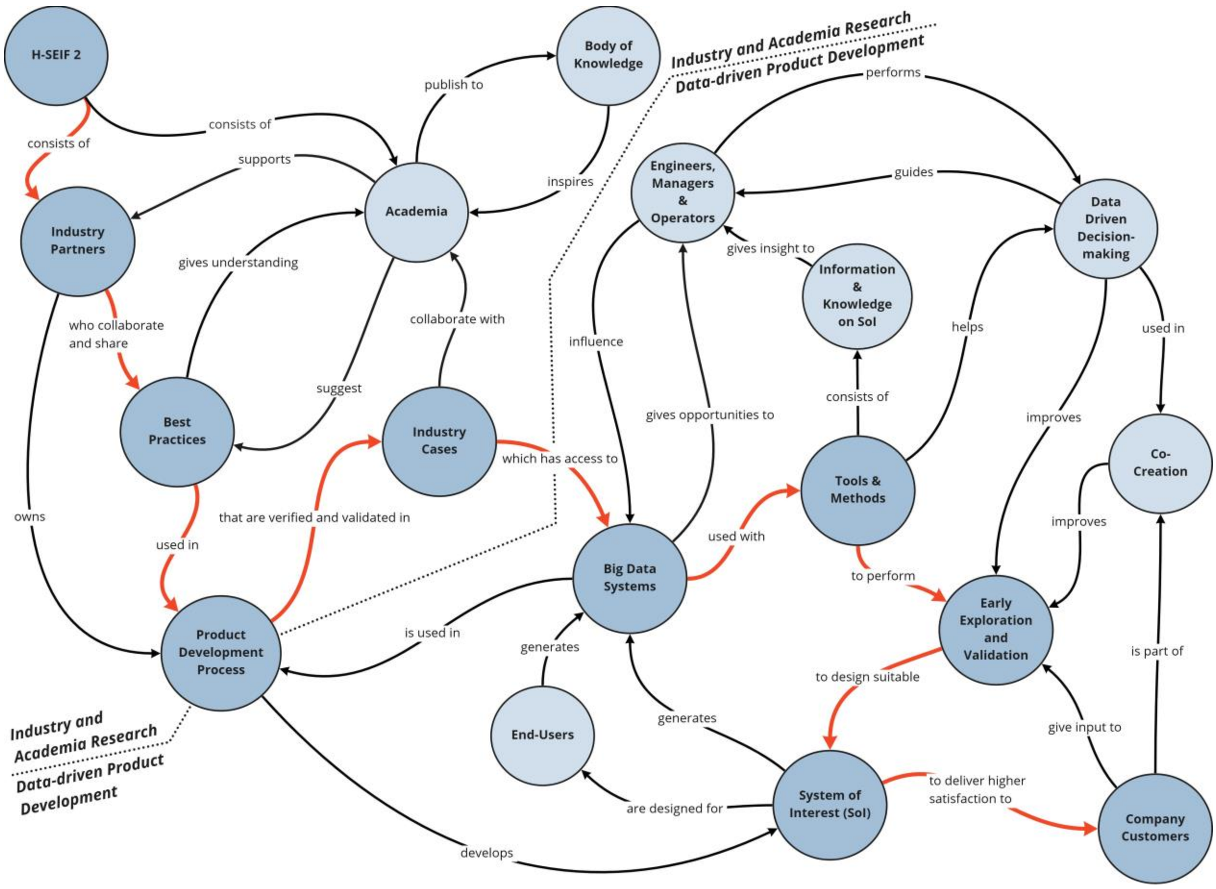

Figure 3. Systemigram of H-SEIF 2

4. Discussion

This section evaluates feasible and desirable leverage points discovered from the systems thinking tools. In the research project, multiple stakeholders are working towards a common goal. We need to learn each other's perspectives and needs. It is easier to achieve project success by taking a direction based on influential leverage points. The authors wish to have the leverage point on a low level, as people are more resistant to change on a higher level. We assume leverage points are feasible and desirable if they tell us what to focus on to gain insight into how companies can utilize Big Data for product development.

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4.1. Industry cases

In the Systemigram (see Figure 3), the industry cases are the key elements in tying the research project and the applications domain. With industry cases, academia can support the companies, having possibilities to learn and explore, and it is possible to verify and validate the suggested solutions. Therefore, it is important that *the companies make available relevant and applicable industry-as-laboratory cases to the research project.*

4.2. Collaboration

The teams related to each industry case need to be motivated and have backing from their company. Additionally, academia has a supporting role in pushing the research forward. The researcher will add resources such as access to scientific papers and subject matter experts. They will also support by exploring and validating the possible solutions. The industry partners will collaborate and share industry best practices, while academia supports them with input from the body of knowledge. This indicates that *the communication and collaboration between the companies, academia, and the industry cases are vital as it gives valuable research input.*

4.3. Big data systems and architecture

A central system in the H-SEIF 2 project is the system of the Big Data, here named Big Data Systems. It consists of the data, software, infrastructure, and architecture. Big Data is the source for the information and knowledge about the systems of interest and their users. For the engineers, managers, and operators to make sense of the Big Data and perform data-driven decisions, it needs to be transformed through tools and methods. *The research project needs competence and capabilities to build Big Data systems and architectures relevant to the industry cases.*

4.4. Socio-technical domain

The objective of H-SEIF 2 is to create a framework for improving their product development process through increased speed, customer satisfaction, and data-driven decisions. Big Data and people are the material and tools to achieve things; however, it is the interaction between the technical and the social world that gives the possibility to create value. On its right side of the Systemigram, we see that the key elements to achieve this goal lie in the socio-technical domain. A part of the research should *emphasize the co-creation between stakeholders, how they make data-driven decision-making based on the Big Data, achieve early exploration and validation, and the tools and methods to achieve this.*

5. Conclusion

This paper uses systems thinking approach to understand and define a collaborative research project focusing on how high-tech companies can utilize Big Data in their product development. The study was performed in cooperation with nine Norwegian companies and two universities. The authors used Boardman Soft Systems Methodology, supported with Openness Diagram, CATWOE, and Systemigram. The paper contributes with a current state and need for these companies. By answering RQ1, we see a need for Big Data and digitalization in the product development process. We present RQ2 through four recommended leverage points for the H-SEIF 2 research project to achieve its goals. Two of the leverage points underlines essential factors for the execution of the research project. The other leverage points look at which research areas should be emphasized. The leverage points are:

- The companies should make available relevant and applicable industry-as-laboratory cases to the research project.
- The communication and collaboration between the companies, academia, and the industry cases are vital as it gives valuable research input.
- The research project needs competence and capabilities to build Big Data systems and architectures relevant to the industry cases.

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- The research should emphasize the co-creation between stakeholders, how they make data-driven decision-making based on the Big Data, achieve early exploration and validation, and the tools and methods to achieve this.

The findings in this paper will guide and influence the research direction of the H-SEIF 2 research project. Future work will follow each of the industry cases in a three-year duration, individually and collectively.

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