Master of Science Thesis
MTTM05 Degree project in Engineering Logistics

Maximizing Value-to-Effort Using Digital Twins in a Rapidly Moving Spare Parts Supply Network

A case- and literature study

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This master's thesis was written during the summer and autumn of 2025 and concludes the author's Master of Science degree in Mechanical Engineering with a specialization in Logistics and Production Management at Lund University, Faculty of Engineering. The thesis has been written in collaboration with the Service Division of a leading Company within the food processing and packaging solutions industry, based in Northern Europe.

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Abstract

Title: Maximizing Value-to-Effort using Digital Twins in a Rapidly Moving Supply Network

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Background: The Company's spare parts network currently operates in functional silos, with teams optimizing their processes independently. This siloed structure limits end-to-end visibility and cross-functional collaboration, causing fragmented information flows and reactive decision-making. As customer excellence is a key performance indicator, the lack of transparency increases the risk of delays, inefficiencies, and unfulfilled expectations. To address these challenges, The Company has initiated the "Command Centre" project, aiming to enhance visibility, coordination, and responsiveness across the network.

Purpose: The purpose of the thesis is to investigate how a Digital Twin (DT) can enable end-to-end visibility, improve decision-making in the spare parts network, and serve as a cross-functional platform that fosters collaboration and breaks down silos. Additionally, the implementation of a DT will be examined through a value-to-effort analysis, and a framework will be proposed to support its adoption.

Methodology: The thesis is based on an exploratory single-case study consisting of 20 semi-structured interviews and a follow-up survey, iteratively combined with a systematic literature review. The research is grounded in the theoretical concepts of Supply Chain Visibility and Digital Supply Chain Surveillance. Specifically, the four pillars of visibility and the SDAR (Surveil, Detect, Action, Response) framework serve as the primary analytical lenses. Furthermore, a Value-to-Effort prioritization matrix is utilized as a strategic lens. Thematic analysis identified key challenges and desired capabilities, while the Value-to-Effort perspective guided the evaluation and prioritization of potential solutions.

Conclusions: The results show that DT technology can address key challenges in the spare parts network, including fragmented systems, reactive processes, lack of visibility, and prioritization gaps. Current operations lack end-to-end visibility and proactive decision-support, limiting responsiveness and in turn reducing customer satisfaction. Applying a value-to-effort lens revealed that quick win capabilities such as integrated order visibility, role-adapted dashboards, threshold-based detection, and action recommendation, offer high value with relatively low effort. At the same time, more advanced features require greater effort but promise transformative benefits. A three-phased implementation roadmap, aligned with an SDAR framework, is proposed to ensure scalability and progressive value creation. Ultimately, DTs can shift operations from reactive to proactive, enabling a customer-centric supply network, and lay the foundation for future automation and predictive capabilities.

Contribution: This thesis has been a complete collaboration between the two authors. Each author has been involved in every part of the process and contributed equally.

Keywords: Digital Twins, Supply Chain Visibility, Surveillance Digital Twin, Spare Parts Network, End-To-End Visibility, Decision Support, Control Tower, Value-To-Effort

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List of Abbreviations

AI – Artificial Intelligence
DSCT – Digital Supply Chain Twin
DT – Digital Twin
EOQ – Economic Order Quantity
FIFO – First-in-First-out
iDT – Intelligent Digital Twin
IoT – Internet of Things
ML – Machine Learning
MOQ – Minimum Order Quantity
RFID – Radio-Frequency Identification
SCV – Supply Chain Visibility
SLA – Service Level Agreement

1. INTRODUCTION

In this chapter, the background for the thesis will be presented, along with a description of The Company. This is followed by the problem statement, as well as the purpose and study's intended objective. Lastly, the research questions and delimitations are introduced.

1.1 Background

A well-functioning supply chain is foundational to any successful organization. Yet as distribution networks become more dynamic and complex, the ability to access and obtain reliable information becomes increasingly difficult. Information is essential for maintaining an effective and functioning supply chain. Information such as arrival times, order quantities, pick locations, lead times, and customer preferences is critical to maintaining efficiency and accuracy. These insights depend on robust collaboration, transparency, and traceability across supply chain actors (Min et al., 2005). All of which contribute to improved visibility across the supply chain.

Visibility across the supply chain has been problematic and a key concern for many organizations for many years. Narrow views and not seeing holistic views in departments within an organization can damage efficiency and, thereafter, profitability. Silo mentality is when different teams don't share enough information, operating independently, which could hinder collaboration, lead to inefficiency, double handling, and declining results (Koolen, 2023). Modern information systems, however, can today provide valuable real-time visibility to combat complexity and uncertainty, ultimately leading to a more transparent supply chain and helping break down these silos (Barratt, 2004).

Supply chain visibility is necessary to gain insight into the market and The Company's operations. Ensuring visibility in the supply chain will also help with strategic and tactical information, allowing employees to lower uncertainty, enhance coordination, and improve customer satisfaction (Barua et al., 2004). Different pillars of visibility can provide capabilities that have the potential to generate competitive advantage and create strategic value (Wei and Wang, 2010). However, true visibility can only be achieved when people, technology, and processes are aligned and work together (Moshood et al., 2021).

The modern supply chain is becoming increasingly more complex and dynamic due to globalization, rapidly shifting customer demand, and technological advancements. Driven by technological advancement and increasing complexity, digitalization has developed into a source of huge value (Alyasein et al., 2025) and can provide benefits along with challenges. Challenges in maintaining a resilient and operationally efficient supply chain. (Li et al., 2025) Digitalization enables firms to automate tasks, analyze large amounts of data, and improve connectivity. This transformation is the backbone of Industry 4.0, often referred to as the fourth industrial revolution (IBM, 2021a).

At its core, Industry 4.0 leverages interconnected technologies such as the Internet of Things (IoT), artificial intelligence (AI) and machine learning, cloud and edge computing, robotics, big data analytics, etc. These tools enable real-time data capture, provide predictive analytics, and improve autonomous decision-making (IBM, 2021b). One significant technology within this framework is the Digital Twin (DT). DT is a virtual replica that can reflect the state and behavior of a physical asset or process in real time. DTs enable manufacturers and organizations to simulate, monitor, predict, and enhance operations, thus helping increase productivity, achieve greater efficiency, better R&D, and improve workflows, etc. (IBM, 2021a).

A DT is a type of cyber-physical system that leverages multiple IoT sensors to create a highly accurate visual representation of a physical asset (object or process). The vast amount of data collected by the DT is integrated and analyzed using machine learning algorithms to support strategic and organizational decision-making. By continuously updating with real-time data to reflect the physical assets' current state and behavior, a DT can help visualize, analyze, optimize, and improve the supply chain (Moshood et al., 2021). DT is a digital tool that represents a step beyond digitalization, and with its capabilities, it can create value for the digital supply chain and enhance end-to-end global logistics. Data shareability and accessibility are key elements regarding the potential of the DT and its degree of influence on a company. To achieve a collective goal on the broader system, collaboration among stakeholders or departments is necessary (Liu et al., 2024). DTs can address key problems related to visibility, transparency, and efficiency within supply chain management. As a result, they enable improvements in the quantity, quality, and management of information across the entire supply chain (van der Valk et al., 2022).

Despite the potential benefits with DT technology, the application of DTs in supply chains remains at an early stage. Le and Fan (2023) emphasizes that research gaps exist, particularly regarding the lack of practical experiment capacity in current DT techniques and methods. Furthermore, Le and Fan (2023) identify crucial implementation gaps, and highlight the need for structured roadmaps along with a deeper integration of emerging technologies to ensure that DTs are transparent, trustworthy, and resilient. To effectively bridge the gap between theory and practice, a Value-To-Effort matrix can be utilized as a strategic decision-support tool. This matrix is a variation of the impact vs effort matrix, based on the work by American Society for Quality (asq.org, n.d.). By utilizing the matrix, DT features can be segmented into categories, allowing organizations to prioritize functionalities that deliver the highest operational value relative to the required implementation effort.

1.2 Description of The Company

The Company is a global provider for food processing and packaging solutions, with origins in Northern Europe. Since its founding in the mid-20th century, it has grown into a leading actor in its field. They have a strong commitment to innovation, quality, and sustainability. To ensure quality and sustainable products, The Company offers cutting-edge solutions for packaging, advanced filling machines, and high-performance processing equipment; each tailored to meet the dynamic needs of food producers and consumers around the world.

The Company's operations are structured into three key areas: Packaging, Processing, and Service. The Packaging division incorporates procurement and distribution of packaging materials all over the world. The Processing division provides the machinery and equipment used to produce cartons and packaging materials. The Service division provides support for the customer on the aftermarket, e.g., spare parts necessary for operating and maintaining machinery. The thesis focus will be on the Service division, specifically the Spare Parts Network. The network is critical in ensuring product availability and customer satisfaction by managing the flow of components and consumables across a global distribution network.

1.3 Problem Statement

The Company currently operates in functional silos, with departments such as purchasing, inbound, outbound, and sales working independently and optimizing their processes. While this may improve local efficiency, it often fails to support the broader objectives of the supply chain. Without unified, end-to-end visibility, decisions made in one function can negatively impact downstream processes. There is currently a lack of cross-functional collaboration.

This siloed approach results in limited visibility across the value chain, making it difficult to deliver timely and accurate information to customers. Customers themselves have limited visibility of where their product is in the supply chain, see Figure 1. As they Service division is customer focused, the absence of transparency not only slows operations but also increases the risk of unfulfilled expectations. To address this, The Company aims to enhance transparency, end-to-end visibility, and coordination through their "Command Centre" project.

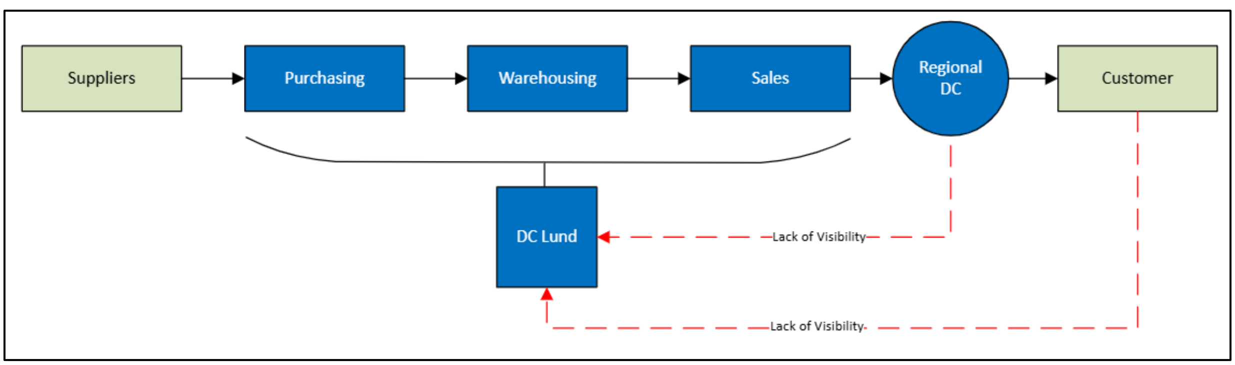

Figure 1: Basic overview of the spare parts network

1.4 Purpose

The purpose of the thesis is to investigate how a Digital Twin (DT) can enable end-to-end visibility, improve decision-making in the spare parts network, and serve as a cross-functional platform that fosters collaboration and breaks down silos. Additionally, the implementation of a DT will be examined through a value-to-effort analysis, and a roadmap along with a conceptual framework will be proposed to support its adoption.

1.5 Research Questions

In this section, the research questions guiding the thesis are introduced. As the concept of Digital Twins (DTs) is relatively new and still emerging within industrial applications, there is limited academic research on practical implementation. Especially regarding the scope and scale in environments such as supply chains. There is a need to better understand where the technology is currently used, how it is applied, and what benefits it brings. This is particularly relevant within the context of a spare parts supply network, where visibility and coordination across functions are critical. However, to even begin exploring the benefits of DTs, it is crucial to map and get a clear understanding of the structure of the spare parts network along with its challenges. This leads to the first research question.

RQ1: *What is the structure of the spare parts network and what current challenges exist regarding end-to-end visibility and cross-functional collaboration?*

Once the structure and challenges within the spare parts network are identified, the next step is to explore, based on literature paired with empirical findings at The Company, how DT technology can create tangible value. In the context of this study, value is defined as the ability of a DT to improve operations such as improved decision-making and break down organizational silos. By considering both the potential benefits that will bring value, and effort connected to implementation complexity through a Value-To-Effort lens, it is possible to determine where the highest value relative to the effort required is. This leads to the second research question.

RQ2: *How can a Digital Twin be used address current challenges problems at the spare parts network, and what is their perceived value relative to the effort?*

Beyond identifying potential benefits, successful DT implementation requires a clear, structured, and feasible implementation strategy. This includes defining phases, ensuring that the solution evolves in line with organizational readiness and technical maturity. By addressing challenges and prioritizing capabilities, The Company can move from conceptual roadmap to reality in a controlled and sustainable manner. Therefore, a roadmap and conceptual framework is needed, which this leads to the final research question.

RQ3: *How can a roadmap and conceptual framework be designed to support the implementation of a Digital Twin at the spare parts network?*

1.6 Scope and delimitations

Despite DTs being relatively new, the application areas in which they can be adopted are wide. To maintain a clear and feasible scope, this thesis focuses only on The Company's spare parts network. The thesis is exploratory and aims to propose an implementation roadmap and evaluate possible application areas concerning the selected key performance indicators given by The Company: Customer Experience (CX), Sales Order Backlog and Service Level. The thesis does not cover detailed system development, technical, or full-scale implementation. Integration with ERP/WMS systems such as SAP will only be considered at a holistic level, and no in-depth technical analysis will be performed. Technologies such as AI, Machine Learning, and IoT will only be explored at a conceptual level to illustrate potential enablers. Blockchain will not be investigated. The data that the DT will be based on is limited to company intralogistics. However, factors like customer experience and supplier performance can be taken into consideration. The Company excluded functions such as returns, quality assurance, HR, etc, due to the restricted relevance to the scope and purpose. Although it is unlikely that new information regarding DTs will emerge during the thesis period, the thesis will maintain a short-term focus. However, scalability may be explored. While the findings may not apply beyond the spare parts network, the findings are expected to offer valuable knowledge for The Company's ongoing digital transformation. Since DTs is a relatively new area, a single case study is appropriate to focus on. A multiple case study would be of interest if it were not for the excessive scope and heavy literature review.

1.7 Thesis Structure

The thesis is divided into different chapters. The following describes the structure of the thesis along with a summary of each chapter.

Chapter 2 – Literature Review
The literature review builds the theoretical foundation for the thesis. It reviews relevant concepts such as supply networks, supply chain visibility and digital supply chain surveillance. Then, it presents Digital Twin technology along with its definition, architecture, benefits, challenges, and surrounding technologies. The chapter is concluded with a conceptual framework that integrates theoretical insights with empirical findings.

Chapter 3 – Methodology
This chapter presents the research design and the process used in this study. It outlines the methodological choices based on Saunders' "Research Onion" including research philosophy, approach, design, and techniques and procedures. It details the data collection methods (literature review, interviews, and survey), the thematic analysis approach, and measures taken to ensure trustworthiness.

Chapter 4 – Empirical Findings
This chapter presents the case study findings, starting with an overview of the spare parts network and its organizational structure. It describes ongoing initiatives related to Digital Twin technology, for example the new planning system and Command Centre project, that in turn will enable the network transformation. The Command Centre will be focused on this thesis. Thereafter, key challenges are identified and desired capabilities for the Command Centre based on the interviews and survey responses are presented.

Chapter 5 - Analysis
The analysis chapter combines insights from the literature review and empirical findings to address the research questions. It evaluates how Digital Twin capabilities can resolve identified challenges and assess the value of implementing a Digital Twin across each function. The chapter also discusses dashboards, detect and predict systems and simulation-based decision support. Lastly, barriers and challenges when implementing a Digital Twin are discussed.

Chapter 6 – Conclusion
The final chapter summarizes the answers to the research questions, presents recommendations for The Company, and outlines an implementation roadmap for the Command Centre and Digital Twin integration. The chapter also discusses limitations, contributions, and suggestions for future research.

Chapter 7 and 8 – References and Appendix
After the conclusion, the references and appendices follow, providing supporting material such as interview guides, survey details, and extended tables containing information from interviews.

2. LITERATURE REVIEW

In this chapter, relevant literature for the master's thesis is reviewed. It introduces supply networks and supply chain visibility, including the benefits and challenges with supply chain visibility, and the concept of end-to-end visibility. Thereafter, the core concept of Digital Twin (DT) technology is presented, covering definitions, architecture, benefits, along with general and implementation challenges. The chapter also introduces Digital Supply Chain Surveillance (DSCS) as a framework for monitoring, detecting, and responding to disruptions. Supportive technologies such as IoT, AI, and Machine Learning is then covered. Finally, a conceptual framework is presented to link literature and empirical findings to the research questions.

2.1 Supply Networks

A supply network, in contrast to a traditional supply chain, represents a more complex, dynamic, and interconnected systems with capabilities of emergence, self-organization, and adaptation (MacCarthy et al, 2022). A traditional linear supply chain has a clear up- and downstream of operations and relies on a focal company to coordinate the flow. A supply network, however, connects multiple supply chains covering different partners or tiers without necessarily directly involving the focal company. The benefits of having a supply network compared to a regular supply chain are driven by the need to optimize cost, time, and efficiency. For instance, in a supply network, a spare part can be shipped directly from a distribution center to a local company, bypassing the focal point, for steps like quality control. If the distribution center could provide quality control on their own, this not only reduces lead times and logistics cost, but also enhances responsiveness to demand from the market (Digitalization Manager, 2025).

However, managing a supply network includes challenges. Greater interconnectivity requires strong collaboration, accurate and timely data, and high visibility across all partners to avoid disruptions. Misaligned objectives, poor data quality, or lack of transparency can undermine performance and increase risk. Ensuring trust, data integrity, and shared goals is therefore critical for smooth operations. These aspects will be further explored in Chapter 4 in the context of The Company and the spare parts network.

2.2 Supply Chain Visibility

Supply chain visibility (SCV) is a concept that has gained increased attention (Kalaiarasan et al., 2022) and has become a crucial part of Supply Chain Management (SCM) research. Due to e.g. increased competition, digitalization, and emphasis on customer satisfaction, SCM has become a critical focus for companies. Companies have long recognized the need to manage the flow of finance, materials, and information across the supply chain. (Barratt and Oke, 2007) Sharing information effectively within a company is important. Therefore, SCV has become a key issue to address since it affects the entire supply chain (Caridi et al., 2014) and can provide plenty of benefits if managed efficiently. However, sharing information does not equal visibility. Therefore, the potential benefits that enhanced visibility can contribute cannot be directly linked to the concept of information sharing. Sharing information is an activity while visibility is the result of said activity. It first becomes visibility after the information provided is verified by the receiver as accurate, trusted, useful, etc. (Barratt and Oke, 2007). Kalaiarasan et al. (2022) combine several early definitions of supply chain visibility and define the concept as "the extent to which actors within a supply chain have access to the timely and accurate demand and supply information that they consider to be key or useful to their operations and supply chains." A high level of visibility is depicted by the quality of the information, and the high level of visibility can in turn lead to sustainable competitive advantage in supply chains. (Wei and Wang, 2010) However, to even consider visibility, it is important to realize the prerequisites or antecedents that enable SCV, the barriers and challenges one can encounter when making improvements, drivers to motivate The Company to improve SCV, and the resulting effects from the higher level of visibility (Kalaiarasan et al., 2022)

To achieve visibility within an organization, there are some factors that are essential. Kalaiarasan et al. (2022) divided these antecedents into three categories: people, process, and technology. People-related factors can include trust, culture, and inter-organizational collaboration. Process-related factors include business alignment, integration, information quality, and of course information sharing. Technology-related factors include collaborative planning systems, connectivity, RFID, and blockchain. These are specific technologies relevant to SCV. RFID has been a key technology since early days, while blockchain has been dominant since 2019 and improved visibility by enabling tracking and tracing of the extended supply chain. Cloud-based collaborative planning systems are critical in enabling end-to-end SCV. Wei and Wang (2010) also address this matter and what benefits it brings. The factors in the three categories are important to consider obtaining superior performance in a fast-moving and fast-changing competitive environment.

In fast-moving business environments, in this case a rapidly moving spare parts supply network, it is important to have the ability to adapt to changing market conditions and technological opportunities. Supply chain reconfigurability is an important capability for companies to focus on to generate competitive advantage in changing environments. (Wei and Wang, 2010) This means that if new conditions occur, resources may need to be reallocated or reconfigured. The precision and efficiency to adapt to new conditions are defined by reconfigurability. Wei and Wang (2010) propose four dimensions of SCV that support supply chain reconfigurability, thereby enhancing strategic performance. The dimensions are visibility for sensing, visibility for learning, visibility for coordinating, and visibility for integrating. Visibility for sensing and learning are two important pillars for sensing and shaping opportunities and threats, while visibility for coordination and integration is important for seizing opportunities.

2.2.1 Visibility Pillars

Visibility for sensing is the first pillar and refers to an organization's ability to quickly access and interpret real-time information from internal operations as well as external conditions to detect and effectively respond to any changes in the environment. It enables firms to anticipate shifts in demand, disruptions, and opportunities, supporting agile and informed decisions (Wei & Wang, 2010) High visibility also allows supply chain reconfiguration to meet customer value demands (Christiaanse & Kumar, 2000). Organizations that share information broadly across the supply chain are better positioned to sense and act on key events, improving responsiveness and resilience (Madhavan et al., 1998).

Visibility for learning refers to the extent to which an organization can acquire and apply new knowledge from both internal and external partners. External knowledge strengthens capabilities, expands the knowledge base, and improves performance (Wei & Wang, 2010). Exchanging ideas within the supply chain reduces uncertainty and supports adaptive changes (Zollo & Winter, 2002). Zollo and Winter (2002) further suggest that learning serves as the basis for building capabilities, specifically from three key mechanisms: experience accumulation, knowledge articulation, and knowledge codification. Experience accumulation is interpreted as the actual learning process, knowledge articulation as the process of converting ambiguous knowledge into a form that can be shared with others, and knowledge codification as the process of taking learnings and applying the knowledge to the organization. Furthermore, frequent interactions and knowledge exchange can further enhance understanding and innovation (Nonaka et al., 2000).

Visibility for coordinating can help supply chain partners recognize the value of their resources and synchronize their activities in new configurations (Iansiti and Clark, 1994). Coordination involves managing dependencies that ensure that decisions that resonate with all parties (Malone & Crowstone, 1994; Simatupang et al., 2004) The dependencies that Malone and Crowstone (1994) identified in the supply chain are prerequisite, transfer, and usability. These dependencies determine how processes rely on each other to ensure a functioning supply chain (Wei & Wang, 2010). Prerequisite dependencies involve aligning upstream orders with downstream shipping notices (Christiaanse & Kumar, 2000). Transfer dependencies can be managed through timely delivery information or inventory buffers, while usability dependencies require understanding customer needs through market research and involving suppliers in product design (Wei & Wang, 2010).

Visibility for integrating focuses on sharing information to achieve joint goals and a collective identity among partners in the supply chain and in turn enable integration of processes and technology. This integration is pivotal for creating strategic advantage by leveraging external activities and technologies (Teece et al., 1997) and enabling a shared understanding. A shared understanding aligns strategies and operations (Dyer, 2000), supports reconfiguration for new challenges, and fosters long-term collaboration through shared meanings and agreements (Gosain et al., 2004; Elgarah et al., 2005)

The supply chain visibility can be broken down into the four mentioned pillars. Each one helps organizations access and make sense of real-time information, whether it is from inside The Company or from partners. These different kinds of visibility make it easier to spot changes, share knowledge, manage dependencies, and work toward shared goals. Together, they give a more holistic view of how the supply chain works and where efficiency is lacking. That is why it is important to look at what affects visibility and the effects when it improves, the benefits, barriers, and challenges.

2.2.2 Benefits, Barriers and Challenges

Supply chain visibility (SCV) is widely recognized as a key enabler of enhanced supply chain performance. By providing access to accurate and timely data, increased SCV allows decision makers at companies to better interpret and respond to changes in both supply and demand (Kalaiarasan et al. 2022; Srinivasan and Swink 2018). This enhanced visibility results in greater agility, greater process control, flexibility, and responsiveness, enabling organizations to adapt quickly to disruptions or shifting customer expectations (Viel de Farias et al., 2022). It also improves forecasting accuracy, planning and replenishment capabilities and decision-making (Barratt and Barratt 2011). SCV contributes to risk mitigation by helping firms detect potential disruptions early and build more resilient operations (Brandon-Jones et al. 2014). Moreover, visibility enhances strategic adaptability by enabling firms to reallocate resources in response to external changes (Wei and Wang 2010).

Building on these capabilities, SCV has been shown to significantly improve supply chain outcomes. Studies link visibility to improvements in cost efficiency, delivery reliability, flexibility, and customer service (Kalaiarasan et al. 2022; Caridi et al. 2014). Organizations with strong SCV capabilities are typically more responsive to market dynamics and better equipped to maintain service levels under pressure. Furthermore, firms with high visibility achieve, for example, elevated profitability and improved sales performance (Swift et al. 2019). Additionally, enhancing SCV plays a critical role in advancing sustainability objectives. By improving transparency and traceability across tiers, SCV enables firms to monitor supplier practices, verify compliance with environmental and social standards, and ensure responsible sourcing. This capability not only mitigates risks such as labor exploitation and environmental violations but also promotes collaboration, traceability, transparency, and trust among supply chain partners. (Dubey et al. 2017; Brun et al. 2020). In this way, SCV is not just a tool for operational efficiency. It is key to improving sustainability (Brun et al. (2020); Wang et al. (2020)) and a strategic asset that drives long-term value. However, while visibility is often presented as an obvious benefit, research shows that information sharing is not universally beneficial (Kembro, Näslund and Olhager, 2024). The benefits depend on the context and simply increasing the volume of information does not always translate to better performance.

Achieving high levels of visibility is not without challenges. The issue often lies not in the absence of data sharing, but in the quality, timeliness, and relevance of the information exchanged (Kalaiarasan et al. 2022). Barriers such as lack of trust, poor system integration, and incompatible IT infrastructure can hinder visibility efforts. Even within a single organization, internal silos and outdated systems can obstruct information flow. Budget constraints, poor data quality, and limited staff training, further complicates the implementation. Efforts that contribute to additional costs such as IT tools, external resources, consulting, and more, can also potentially form barriers and prevent organizations from enabling visibility (Swift et al. 2019). The overall complexity of a network can also be too broad, making End-to-End visibility difficult to achieve. Externally, smaller suppliers may not have the capacity to achieve total supply chain visibility since it can require far too great investment (Yu and Goh, 2014). These challenges highlight that realizing the full potential of SCV requires more than just technology. It demands organizational alignment, trust, and a shared commitment across the supply chain.

2.2.3 End-to-End Visibility

End-to-end supply chain visibility entails the ability to see and understand the supply chain process in its entirety, from the procurement of materials from supplier to delivery of goods to customers, i.e. full observability (Nafar, 2021). The concept of End-to-End visibility is crucial for a broader scope of today’s global and complex supply networks. With End-to-End visibility, firms can detect disruptions early even when they are external, better coordinate with partners, and respond faster to fluctuating conditions. Nafar (2021) also claims SCV is an enabler of supply chain reconfigurability, and that it is an important dynamic capability for supply chains. Wei & Wang (2010) in turn, states that reconfigurability is important to generate competitive advantage.

One practical example of End-to-End visibility is the World Food Programme’s (WFT) Supply Chain Management Dashboard (SCM-D). SCM-D is a tool that aggregates and condenses data from various locations across the supply chain and provides one holistic overview of key information for an operation. The dashboard is an easy-to-use platform where simplicity is key. It breaks down complex supply chain information in way that is detailed enough to provide insight into the operation, including risks, potential disruptions, challenges and opportunities, while still offering a broad perspective that captures a clear view of End-to-End activities. Additionally, it improves transparency, efficiency, facilitates collaboration and supports better informed decision-making across functions (Sithole et al., 2016). These are, inter alia, critical for achieving supply chain resilience and robustness. The SCM-D can be seen as a precursor to how a Digital Twin (DT) enhance supply chain visibility and cross-collaboration even further. With a DT, the dashboard could display real-time monitoring of the real-world counterpart, predict outcomes, and help the decision-making process. (Iranshahi et al., 2025) Ultimately, End-to-End visibility is not just about having access to data, it is about turning that data into actionable insights that lead to better decisions and stronger performance across the entire supply network.

2.2.4 Supply Chain Resilience & Robustness

Closely connected to visibility is the resilience and robustness of the supply chain. Resilience and robustness are two essential capabilities in managing supply chain risks and are increasingly important for supply chain managers. Resilience refers to the ability of a supply chain to recover and return to normal operations after disruption, while robustness refers to the ability of a supply chain to maintain performance despite disturbances (Brandon-Jones et al. 2014). Visibility is a key capability in enabling both and reducing supply chain risk. Visibility is paramount as an antecedent to risk reduction, not only for its ability to track products and identify potential disruptions, but also because the lack of visibility can create new risks (Brandon-Jones et al. 2014). Brandon-Jones et al. (2014), states that visibility is developed through two critical resources: connectivity and information sharing. Connectivity refers to the technological infrastructure that supports communication across the supply chain while information sharing is about the nature, speed, quality, and relevance of the data exchanged. These two are closely related. Without connectivity, information cannot be shared effectively. Whilst without quality information, connectivity adds little to no value.

Together, the two elements form a visibility capability that helps firms detect risks early and manage them more quickly. Kalaiarasan et al. (2022) highlights that low visibility significantly restricts a company's ability to build supply chain resilience. Wei and Want (2010) states that risk management is a prominent driver of SCV. They further argue that SCV will be required to enable visibility for sensing, learning, and coordinating as mentioned in section 3.2.1. This is particularly important in complex networks, where disruptions can spread quickly and unpredictably. When information is shared in a timely and accurate way, and when systems are in place to support that flow, companies can identify bottlenecks, anticipate shortages, and coordinate responses more efficiently. Digitalization is now enhancing this further. By integrating Industry 4.0 technologies such as DTs, companies can improve resilience and achieve end-to-end supply chain visibility (Ivanov et al., 2019).

2.3 Digital Twin

Since the era of COVID-19 a push towards Digital Twins (DTs) has been ongoing. This has been a cause of many factors, for example increasing globalization, rising customer expectations, double-digit shipping growth, supply chain complexity and much more. Therefore, tools to address these problems are necessary and one of these tools is the Digital Supply Chain Twin (DSCT). The DT market is expected to rise around 30 to 40 percent annually for the next few years and eventually reach $140 billion by 2032 according to a market analysis from McKinsey (Oca et al., 2024).

As mentioned in the introduction a DT is a cyber-physical system that uses real-time data and machine learning to mirror real-world assets and processes with real-time accuracy. This continuous updating enables visualization, analysis, optimization, and improvement of supply chains (Moshood et al., 2021). Beyond digitalization, DTs enhance data shareability, accessibility, and collaboration across stakeholders, creating value for digital supply chains and global logistics (Liu et al., 2024). They address core challenges of visibility, transparency, and efficiency, thereby improving the quality, quantity, and management of supply chain information (van der Valk et al., 2022)

A notable early example of a DT is NASA's use of 15 simulators during the Apollo 13 mission to train astronauts and mission controllers. This initiative laid the foundation for what could later be known as DTs, a concept introduced by NASA and subsequently integrated into the aerospace sector's 2010 technology, were essential when simulating spacecraft conditions, exploring potential solutions, and forecasting outcomes, thereby supporting mission planning, design, operations, and management roadmap. (Le and Fan, 2023)

2.3.1 Definition for a Digital Twin

DTs have been defined in many ways, often depending on the context of which is it used. A widely accepted definition describes DTs as a virtual representation of physical assets NASA originally defined it as "An integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or systems that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin." (Glaessgen and Stargel, 2012). Another more comprehensive definition from IBM is as followed: "A digital twin is a virtual representation of a physical object or system that uses real-time data to accurately reflect its real-world counterpart's behavior, performance and conditions." (Armstrong, 2020). DTs enable design, modeling, visualization, testing, and implementation of new ideas without disrupting existing processes.

As can be seen in Table 1 there is currently no single understanding of what a Digital Twin constitutes (Gerlach et al., 2021). Some common themes across all the definitions are real-time synchronization with physical system, continuous data flow, simulation and prediction capabilities, decision support, integration with other tools and systems, lifecycle evolution, goal: optimization resilience, visibility. However, for the DSCT this thesis will use the following definition: *"A DSCT is a model that can always represent the network state in real-time for any given moment and interacting with other SCM tools provides a control tower for complete end-to-end SC visibility to improve resilience and test contingency plans."* (Ivanov et al. 2019) since it includes the most important characteristics and deemed most suitable for this the context, objective, and scope of the thesis.

Table 1: Definitions of various versions of a Digital Supply Chain Twin

Source	Definitions of Digital Supply Chain Twins	Key Characteristics
Korth et al. (2018)	*"DT can therefore be characterized in the following way: it is a linked collection of different types of data (like operation data) as well as different models; it evolves with the real system along its life cycle; it is able to derive solutions relevant for the real systems (e.g., optimize operation and service)."*	Different data sources Different types of models Create solutions for real systems
DHL (2019)	*"In logistics, the ultimate DT would be a model of an entire SC network. (…) DTs are virtual models of a real "thing"; virtually represent a unique physical asset. DTs simulate both the physical state and behavior of the thing. DTs are unique, associated with a single, specific instance of the thing/physical asset. DTs are connected to the thing, updating themselves in response to known changes to the thing's state, condition or context; continuously collect data (through sensors) and being connected to the physical asset, updating themselves with any change to the asset's state, condition or context. DTs provide value through visualization, analysis, prediction or optimization."*	Model of an entire SC Network Virtual model of physical assets Data collection via sensors Visualization, analysis, prediction or optimization
Ivanov et al. (2019)	*"A DSCT is a model that can always represent the network state in real-time for any given moment and interacting with other SCM tools provides a control tower for complete end-to-end SC visibility to improve resilience and test contingency plans."*	Represents the network Real-time updates Control tower End-to-end visibility Enables advanced tools Improves resilience
Marmolejo-Saucedo (2020)	*[. . .] we can define a supply chain digital twin as a detailed simulation model of an actual supply chain which predicts the behavior and dynamics of a supply chain to make mid-term/short-term decisions. Consists of six layers: the physical twin, the local data source, local data repositories, IoT gateway interfaces, Cloud-based information repositories and the emulation and simulation platform.*	Simulation of a Supply Chain Dynamics Different data sources IoT
Gerlach et al., (2021) - Digital Supply Chain Twins—Conceptual Clarification, Use Cases and Benefits	*"A digital logistics twin or digital supply chain twin (DSCT) is a digital dynamic simulation model of a real-world logistics system, which features a long-term, bidirectional and timely data-link to that system. The logistics system in question may take the form of a whole value network or a subsystem thereof.* *Through observing the digital model, it is possible to acquire information about the real logistics system to draw conclusions, make decisions and carry out actions in the real world. The DSCT enables the use of diagnostic, predictive and prescriptive methods with the ultimate goal of holistically improving the logistics performance along the whole customer order process."*	Digital dynamic simulation model Long-term, bidirectional, timely datalink Represents whole network Enables advanced tools

2.3.2 Current state of Literature surrounding Digital Twins

The interest in the combination of DTs and supply chain literature has been growing rapidly since 2018 when the first article using both as keywords was published, see Figure 2. While the research has been growing it is still in its infancy and thus a few research gaps remain. During the literature review it has been identified that a clear general structure to the implementation of DTs in a supply chain does not exist along with a general framework and architecture. This is also reiterated by Le and Fan (2023) who also performed a literature review and found DT gaps in vital industry sectors, implementation roadmap and management, and advanced methods and techniques. Figure 2 depicts the number of articles published each year, that can be found in the Scopus database and that meets the following search criteria:

KEY(("Digital twin" OR "Digital Twins") AND ("Supply Chain" OR "Logistics")) AND PUBYEAR > 2017 AND PUBYEAR < 2026

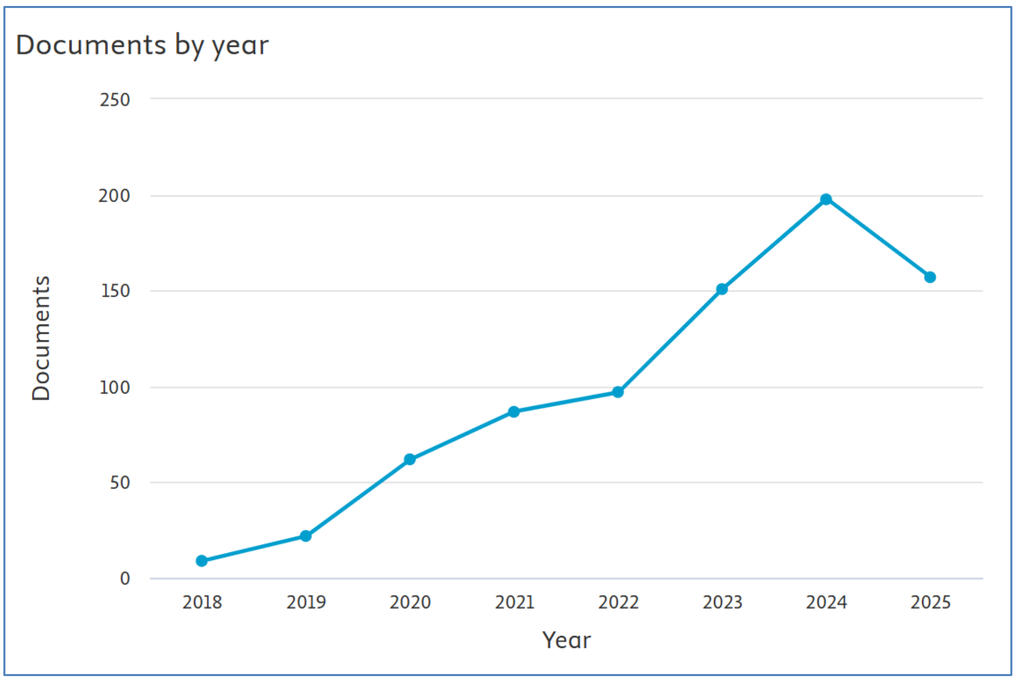

Figure 2: Articles published annually, obtained August 2025

2.3.3 Digital Twin Architecture

The architecture of a Digital Twin (DT) is generally described to have three fundamental layers; the physical, the communication layer and the digital layer (Le and Fan, 2023). The Physical layer encompasses real-world data, decisions, and actions. The communication layer facilitates data transmission and the conversion of real-world data into machine-readable formats and vice versa. The digital layer involves computational and simulations tools for processing data, conduction analyses, and generating predictions. Understanding these layers provides a foundation for exploring how DTs can differ in their interaction with systems, as the degree of integration determines its applications and capabilities.

DTs can be classified based on their level of integration with physical systems. Kritzinger et al. (2018) introduced a widely used framework that distinguishes between three types of digital objects and is reiterated by Grieves (2023). The different types can be seen in Figure 3. The first is a digital model, it operates independently without automatic data exchange. All inputs are manual, and changes in the physical system do not affect the model. The second is a digital shadow, it receives real-time data from the physical system, so changes in the physical object are reflected digitally though not vice versa. Lastly, the DT features a bidirectional data flow. Allowing both the digital and physical systems to influence each other. It can dynamically adjust operations in real time.

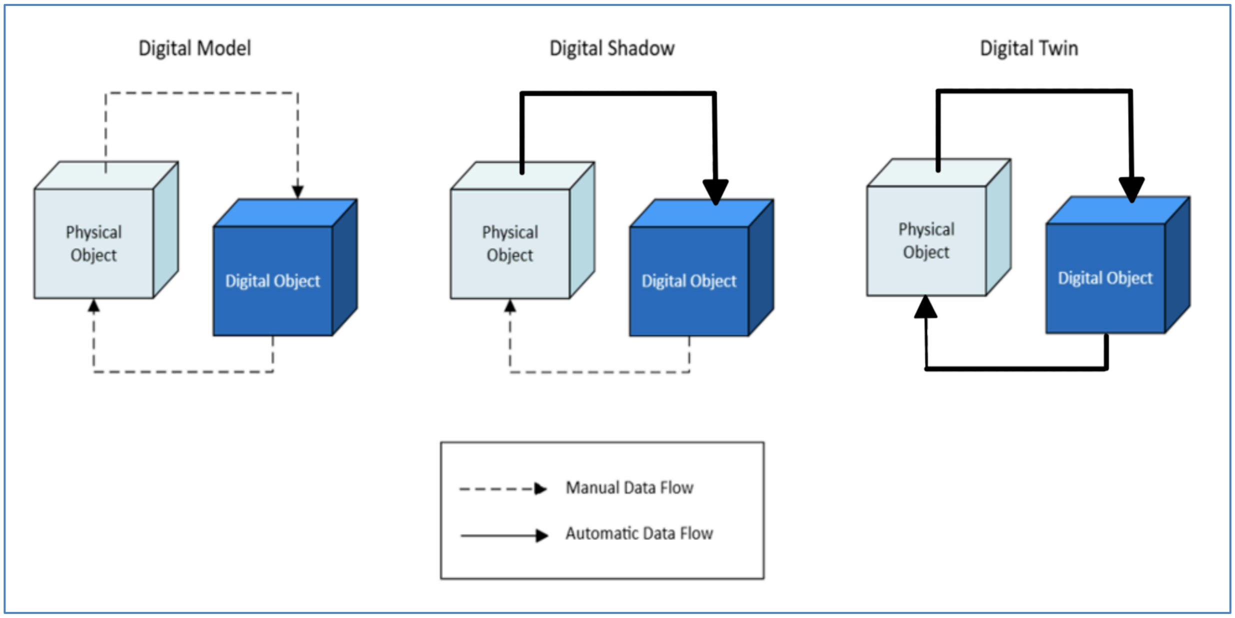

Figure 3: Visualization of Digital Model, Digital Shadow, and Digital Twin (Grieves, 2023, page 1)

The DT can also be described as having three levels of intelligence and is shown in Figure 4, with the first level being the standard DT. This is the level that visualizes the physical supply chain, collects data, process data, and uses the data for modeling. On top of the DT level, a cognitive DT can be built. This layer mimics human decision-making rules and can suggest supply chain solutions. The suggested solutions are based on what decisions the managers have previously made in the past. The third and final level is an intelligent DT (iDT). Here the DT does not only mimic human decision making but can also create new knowledge and decision-making algorithms through self-learning and human-AI collaboration. This is also the level where the iDT can take over a part of the decision-making process (Ivanov, 2025).

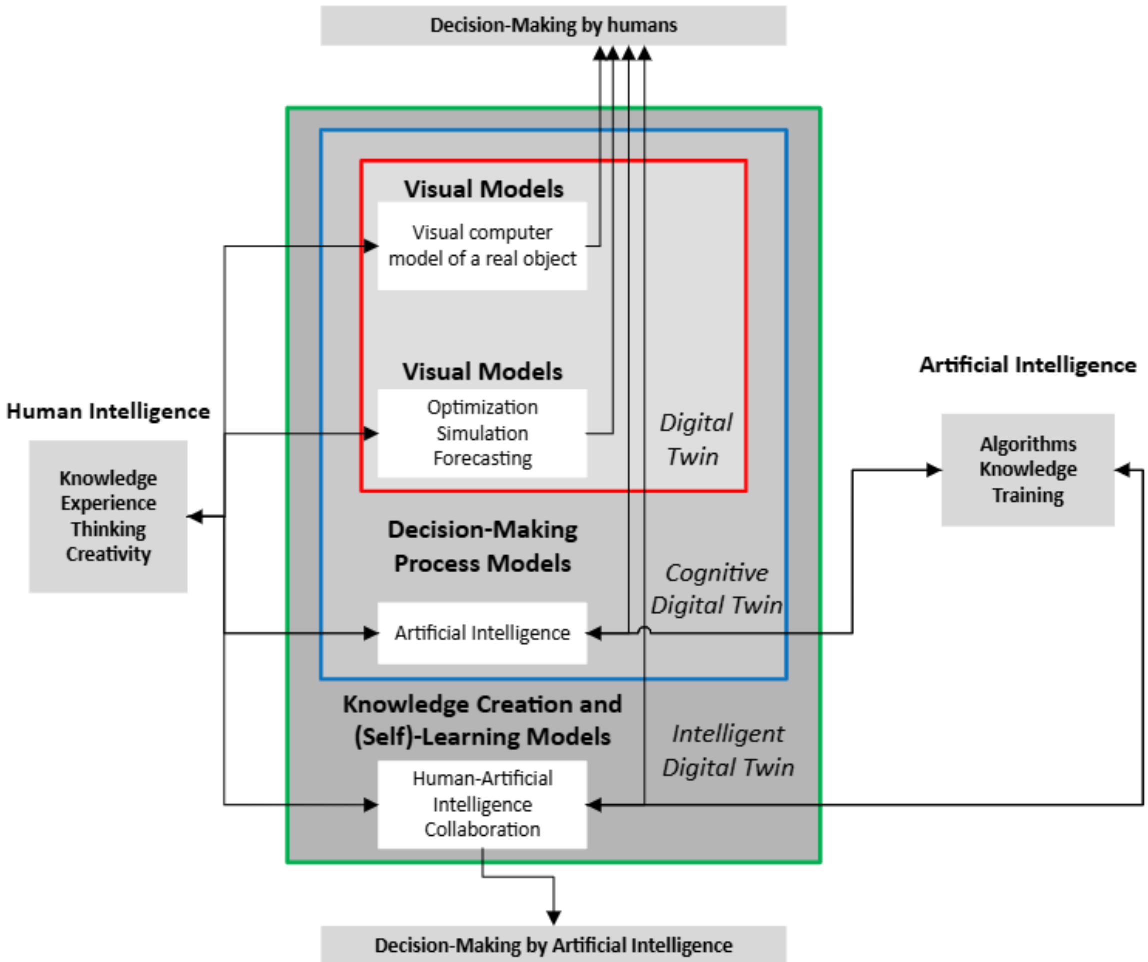

Figure 4: The three levels of DTs (Ivanov, 2025, page 2)

2.3.4 Benefits and use cases

Digital Twins (DTs) can yield significant benefit across societal economic, business and environmental domains. In the context of logistics and supply chain systems, DTs enhance modeling, simulation, operation, and management by integrating diverse data sources, models, and stakeholder interactions. As these interactions deepen, communication becomes more efficient, leading to improved operational performance. This results in faster and more reliable delivery of goods, particularly critical for time-sensitive items like perishable products and machine spare parts when machinery is down. (Le and Fan, 2023)

Given the wide range of DT applications, the benefits vary greatly depending on the context. Therefore, the literature review will focus on the benefits most relevant to spare parts networks and similar supply chain environments. Gerlach et al., (2021) provides a useful framework who distinguish the difference between network- and site-level benefits. One major benefit identified across both network level and site are increased visibility. On a network level, DTs enable end-to-end visibility and transparency of inventory, production and flows involving several logistics parts, suppliers, and customers. On a site level, the increased visibility supports real-time monitoring of production lines, warehouses, and cargo terminals.

Beyond visibility, DTs can contribute to increased supply chain flexibility and resilience. DTs can enable rapid responses to disruptions and support robust operations, which in turn help reduce lead times, lower inventory levels, and eliminate bottlenecks. DTs also enhance risk management through real-time surveillance and simulate "what-ifs" scenarios, allowing organizations to anticipate, prepare for and mitigate potential disruptions. Furthermore, DTs offer functionalities such as performance assessment, decision recommendations, process mining, and control and alert mechanisms (Ivanov, 2025), which align closely with the Detect & Action steps in the SDAR framework further explained in section 2.4. In addition, DTs can provide tools to assess ecological impact, improve material efficiency, reduce waste, and evaluate different scenarios with sustainability metrics. By simulating different scenarios with sustainability metrics, the user can make better decisions that align with environmental goals. These capabilities contribute to benefits such as supply chain transparency and ecological sustainability (Gerlach et al., 2021).

Another important benefit is the possibility to facilitate cross-functional collaboration. DTs can provide a shared environment for decision-making, enabling users to work together more effectively. Building on this, DTs can go beyond standard visibility through operational monitoring by creating a real-time virtual presentation of the network elements (Sani et al., 2024). Organizations can utilize the virtual presentation together with integrated data and predictive capabilities to synchronize supply and demand, optimize allocation of resources, and ultimately work proactively instead of reactively. Furthermore, while visibility is a recurring theme, it is not one-dimensional. As mentioned in section 2.2.1, visibility consists of four key pillars: *sensing, learning, coordinating, and integrating* (Wei & Wang, 2010; Moshood et al., 2021). *Visibility for sensing* refers to an organization's ability to quickly detect internal and external changes, in turn improving responsiveness and resilience. DTs can magnify this through their real-time data capture and scenario simulation capabilities. *Visibility for learning* refers to the extent to which an organization can get and apply new knowledge from both internal and external partners, enabled by feedback loops and predictive insights. DTs amplify this by the capability to track processes and reveal inefficiencies. By highlighting the inefficiencies, companies can learn from them. *Visibility for coordinating* ensures that activities across the supply chain are aligned. DTs enable this through a shared and unified platform where collaboration can be streamlined. A fully integrated DT can for example, reorganize whole logistical flows. Lastly, *visibility for integrating* focuses on sharing information, connecting processes and technologies, to achieve a collective identity and common goals. DTs can magnify this by enabling a unified digital environment (Moshood et al., 2021). Moshood et al. (2021) further points out that DTs can combine predictive, analytical, and diagnostic capabilities, in turn making them a strong enabler for strengthening supply chains and making them agile, resilient, and sustainable. DTs can turn visibility into a strategic advantage and help organizations maintain their competitive edge.

At a site level, DTs support various use cases such as warehousing and cargo handling. In warehousing, DTs can assist by mirroring the physical environment and layout of a warehouse or distribution center in real time. This allows managers to continuously monitor operations and test changes through simulation before applying changes, reducing errors and delays. Thus, acting as a decision support tool (Agalianos et al., 2020). DTs collect the data, process it in a virtual domain, and thereafter make the decisions that realize value (Iranshahi et al., 2025). Additionally, DTs can enhance material handling by enabling efficient planning and control the throughput in highly automated systems (Ashrafian et al., 2019). In cargo handling, DTs can represent cargo terminals within a handling location (e.g., airport cargo terminals), and incorporate load carriers, infrastructural elements, and the cargo itself. The primary goal is to maximize volume utilization by positioning cargo efficiently while considering specific requirements. Load planner can use the DT to refine load plans through simulation, in turn ensuring optimal integration not broader supply chain processes (Gerlach et al., 2021).

Beyond warehousing and cargo handling, DTs offer a wide range of use cases and offer value in boarder supply chain functions. One such area is transportation planning. In transportation planning, DTs can visualize the supply chain with nodes, routes, and dynamic processes. They can forecast near-future location of assets, enabling rerouting, modal shifts, and adjustments to load factors and vessel speeds (Ambra and Macharis, 2020). In risk management, especially with iDTs, organizations can gain access to real-time monitoring, predictive forecasting, and predictive decision-support. Through AI-driven models, iDTs can generate accurate forecasts for purchasing costs, delivery punctuality, and demand fluctuations. These insights can then be fed into optimization modules that recommend supplier selection, inventory adjustments, order allocation, or network redesigns. This proactive approach improves decision-making quality, significantly reduces the time spent on risk-related tasks, and strengthens overall resilience. Additionally, iDTs can free human decision-makers from repetitive tasks, allowing them to focus on more time-consuming tasks such as strategic oversight.

In conclusion, DTs offer a wide range of benefits across both network and site levels, with visibility serving as a central theme. By enhancing the four pillars of visibility, DTs strengthen organizations to operate better and become more efficient, sustainable, and resilient. Through the different capabilities such as real-time monitoring, simulation-based planning, or predictive analytics, DTs can become critical tools for the supply chain, especially in the context of spare parts networks where speed, availability, and reliability are essential.

2.3.5 Challenges

Despite the potential of DT technology (Oca et al., 2024), its implementation within supply chains is associated with several challenges. These challenges can be categorized into technical and data-related issues, infrastructure and integration barriers, cost and resource constraints, and organizational factors. (Attaran and Celik, 2023)

A fundamental foundation for a functional DT is the availability of accurate, timely, and standardized data. However, data standardization remains a major obstacle, as organizations often operate with heterogeneous systems and formats. This lack of uniformity complicates interoperability and increases the risk of inconsistencies. Furthermore, data management becomes increasingly complex as DTs require the processing of large volumes of real-time data from multiple sources (Attaran and Celik, 2023). Ensuring data security and privacy adds another layer of complexity, particularly when cloud-based solutions are employed, as these increase exposure to cyber threats and unauthorized access (Laxmi Pandit Vishwakarma and Singh, 2023). Additionally, the absence of a standardized modelling approach for DT development creates ambiguity and hinders scalability across different contexts (Attaran and Celik, 2023).

Legacy IT systems present a significant barrier to DT adoption. Many organizations rely on outdated infrastructure that cannot support the computational and connectivity requirements of DT solutions. Integration with existing systems and proprietary software is often challenging, requiring substantial customization and middleware solutions. Moreover, the complex architecture of DT systems, which involves multiple layers of physical, communication, and digital components, demands advanced technical expertise and robust governance frameworks (Attaran and Celik, 2023).

The high cost of deployment is frequently cited as one of the most critical challenges. Implementing DT technology requires substantial investment in sensors, IoT devices, software platforms, and supporting infrastructure. Beyond initial development, maintenance costs for ensuring system reliability and performance remain significant. Furthermore, DTs expose an increased demand for computational power and storage capacity, which can strain organizational resources, and elevate operational expenses. (Attaran and Celik, 2023)

Beyond technical and financial considerations, organizations face barriers to implementation related to change management and cultural resistance. Transitioning from traditional processes to DT-enabled operations often requires redefining roles, responsibilities, and decision-making structures. Additionally, the shortage of skilled professionals with expertise in DT development, data analytics, and cyber security further complicates adoption (Laxmi Pandit Vishwakarma and Singh, 2023). Finally, aligning stakeholders around a shared vision for DT integration is essential but often difficult, particularly in global supply networks characterized by diverse priorities and governance models (Le and Fan, 2023).

2.4 Digital Supply Chain Surveillance

DTs can, together with software agents that collect information about operations and systems, constantly monitor a supply chain operation. Combined, these can predict and proactively handle disruptions, uncertainties, and manage potential risks. One example of a solution leveraging AI and DT technology to monitor supply chain operations is Surveillance Digital Twin (DT) (Cam.ac.uk, 2023). This solution is closely linked with the practice of “Digital Supply Chain Surveillance (DSCS)”.

DSCS is a practice to proactively monitor data, in turn allowing firms to easily track, manage, and analyze data and information related to a supply chain network (Brintrup et al., 2022). It involves three key stages: data collection and processing, data analysis, and extraction of actionable insight. The initial data collection and processing stage involves identifying suitable data sources and thereafter formulating methods or algorithms to collect the data. The second stage involves analyzing the data and discovering significant statistical patterns. The last stage is about extracting relevant information and insights that in turn can support improved decision-making related to the challenges. (Kosasih and Brintrup, 2022). Other early warning and risk mitigation algorithms were researched by Aljohani (2023).

To address the challenges of supply chain management in a digital context, a structured approach is needed to guide monitoring, risk identification, and decision-making. This structure is provided by the SDAR framework, which stands for Surveillance, Detection, Action, and Response. The relationship between them can be seen in Figure 5. Unlike conventional supplier management which strategically manages supplier relationships, by monitoring and analyzing the individual suppliers' performances (Lambert and Schwieterman, 2012), the SDAR framework focuses on surveilling at a network level and can be applied to several areas such as production planning, inventory optimization, cost reduction in supply chains, etc. (Brintrup et al., 2022) As the framework is more suitable for overlooking the system at a network level it corresponds better to the structure of the spare parts network and the Command Centre project and will therefore be highly relevant during the case study section of this paper.

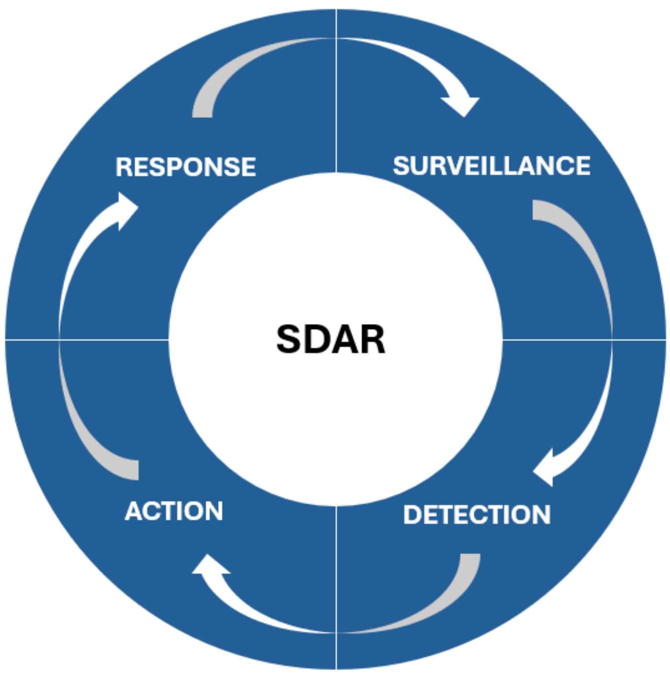

Figure 5: SDAR Framework (Brintrup et al., 2022, page 381)

As mentioned, the framework includes the following four steps: Surveillance, Detection, Action, and Response. *Surveillance* is the first step and entails determining what entities, resources, or activities should be monitored and establish the unit of analysis. This could be endogenous (internal) and exogenous (external) data. Endogenous data can be from ERP, on supplier performance while exogenous data could be through social media or news outlets, for example severe weather conditions or tariffs leading to supplier disruptions (Gabellini et al., 2025; Kosasih and Brintrup, 2022; Grossman and Helpman, 2020). Data collection is critical, but it could also be challenging due to issues of quality. To ensure that the collected and monitored data is relevant, a strong foundation and clear frame of reference is essential.

The next step of the framework is *Detection*. Detection involves identifying deviations, changes, or emerging risks within the monitored data. This could be too long lead times, or disruption alerts from exogenous sources. There are AI tools and techniques that can help detect changes, but human judgement remains most important and vital for validation. The AI tools should therefore be there to complement humans with decision making. (Brintrup et al., 2022)

After a deviation has been identified, organizations must determine what *Actions* to take and what areas or functions are impacted. To have effective alerts, it is important to reiterate that a strong surveillance foundation and clear frame of reference is essential. Examples of suggested actions vary on the situation and detected abnormality, but could for example include rerouting transportation, auditing suppliers, or adjusting inventory. (Brintrup et al., 2022)

After deciding on what actions can be taken, the next and last stage of the SDAR framework is *Response*. Response is the execution phase, where an action is chosen and implemented, and responsibilities assigned. However, the feasibility and expected impact for each of the proposed actions are evaluated before proceeding with the final execution. To ensure traceability, documentation and accountability are necessary. After the response step, the loop is closed and the frame for surveillance can be adjusted for future surveillance cycles, based on the previous learnings. This framework and process strengths the resilience of the organization and encourages continuous improvement. (Brintrup et al., 2022)

2.5 Supportive Technology

Digital Twins (DTs) do not operate in isolation. They rely on a set of enabling technologies that provide the foundation for their functionality. Understanding these enabling technologies is essential to grasp how DTs acquire, process, and utilize data to create accurate virtual representations of systems. At their DTs involve three main aspects: data acquisition, data modeling, and data application. These aspects are supported by technologies that enable real-time data collection, advanced analytics and scalable computational resources.

Three technology areas stand out as enables for supply chain DTs, these are Artificial Intelligence, Internet of Things, and Cloud Computing. These areas are important to grasp to get an understanding of DT technology. IoT can deliver the sensory layer for real-time acquisition, AI deliver analytical and decision-making capabilities and cloud computing ensures the scalability and computational power required to process vast datasets. There are many more supporting technologies, but these were identified as extra important.

2.5.1 Artificial Intelligence & Machine Learning

Artificial Intelligence is transforming supply chain management, enabling businesses to streamline processes, optimize performance, and drive innovation across different disciplines. Under the umbrella term of AI there exist several technologies such as machine learning, natural language processing, and robotic process automation. These technologies offer companies opportunities to enhance efficiency, improve decision-making, and achieve competitive advantage. (Jha et al., 2021)

Machine learning is currently one of the fastest growing fields in science. It combines elements of computer science and statistics. It can be described as a computer system that improves its performance through experience (Jordan and Mitchell, 2015). Although the terms artificial intelligence and machine learning are often used interchangeable, machine learning is a subset of AI. AI refers to the entire field of artificial intelligence, while machine learning specially refers to systems that learn from data (Agrawal, Gans and Goldfarb, 2019). Machine learning has a wide range of applications, including speech recognition, computer vision, natural language processing, and robotic control. In many cases, it is more effective to train algorithms using example inputs and outputs rather than manually programming them. Today, machine learning is increasingly being adopted across various industries such as healthcare, education, engineering, marketing, customer service, and logistics (Jordan and Mitchell, 2015).

Using supervised regression models, it is possible to forecast whether an order line will be late based on features such as order quantity, supplier ID, material type, and historical delivery performance. In a similar manufacturing environment, Steinberg et al. (2023) achieved an R2 of 92% in predicting supplier delivery delays using ERP data. Their model enabled identification of delays immediately after a purchasing request was created, allowing for cost-effective reactive measures and inventory planning. Table 2 summarizes potential ML applications across different functions in the spare parts network, aligned with the DT architecture. Each application is based on earlier application examined by an academic study.

Table 2: Possible applications of machine learning for prediction using the digital twin.

Function	Type of Disruption	Detection method	Data Required	Data Source	Source
Purchasing/ Replenishment	Late supplier deliveries (purchase order delays)	Machine-learning predictive analytics (supervised regression) to forecast and flag late deliveries before they occur. For example, models predict the severity of supplier delays early in the purchasing cycle, enabling proactive intervention	Historical purchase order records (order dates, promised dates, quantities), supplier lead-time history, past delivery performance data. May also include contextual features like part category of supplier ID	ERP procurement system and supplier performance databases. Integrated data from ERP and supplier portals provides training and input for anomaly detection.	(Steinberg et al., 2023)
Inventory Management	Demand surge or forecasting error (stockout risk)	Statistical outlier detection on demand and inventory time-series data. For example. Applying an interquartile range (IQR) filter or control chart to identify abnormal spikes/drops in demand before they cause	Historical sales order volumes and inventory levels over time (to establish normal patterns and detect outliers). May use real-time sales data for immediate anomaly flags during	ERP sales & materials management modules; demand planning systems. Data from order management and inventory records provides the time-	(Wang and Gong, 2025)

		stockouts. Outlying demand data is "smoothed" or flagged so planners can adjust forecasts and safety stocks.	promotions or unexpected spikes.	series for detecting anomalies in demand vs stock.	
Warehousing	Inventory record discrepancies (missing or misplaced stock)	Unsupervised anomaly detection on warehouse stock data. One approach uses isolation Forest algorithms on periodic stocktaking records to automatically flag discrepancies. Real-time event processing raises alerts if scanned inventory counts deviate from book records, enabling quick investigation of missing items.	Structured warehouse data: item IDs, batch numbers, bin locations, and scan counts. Requires continuous updates from barcode/RFID scans and the latest inventory ledger from the WMS/ERP.	Warehouse management system and ERP inventory module. Barcode/RFID scanning data feeds the anomaly detection system often supplemented by a real-time event streaming platform for immediate alerts.	(Tong, 2025)
Customer Service/ Order Fulfillment	Late customer delivery (order not delivered on time)	Control-tower real-time monitoring with complex event processing (CEP). A digital supply chain control tower correlates order events and tracking data to detect delivery delays, using multi-level alert thresholds for lateness. If an order is behind schedule, automated alerts and workflows are triggered to expedite recovery or inform customers.	End-to-end order and shipment status data: order creation and promised delivery date, warehouse dispatch time, last-mile GPS tracking updates, and delivery confirmations. Pre-defined SLA thresholds (e.g. allowable delay) are needed for rule-based alerts.	Order Management System, warehouse and TMS tracking systems, and CRM. A centralized "control tower" system integrates these data stream, often leveraging CEP engines to detect exceptions in real time.	(Chakraborty, 2025)

The application area of AI in supply chain is immense, especially with today's landscape of dynamic and increasingly complex supply chains. One application is with demand forecasting which utilizes machine learning algorithms, another is detection of defects using computer vision models and for logistics, foundation models can be used to design the supply network, acting as decision support. (Nicoletti and Appolloni, 2025)

2.5.2 Internet of Things

The Internet of Things refers to a network of interconnected objects, often embedded with sensors and intelligent systems, that can communicate and exchange data. By integrating numerous devices through embedded systems, IoT enables seamless interaction between machines and between humans and devices (Xia et al., 2012). This connectivity opens new possibilities for visibility, adaptability, and efficiency across various domains, from smart homes to complex supply chains. In supply chains, for example, data collected from disturbed sensors can be analyzed to detect potential issues early and alert human operators (Ben-Daya, Hassini and Bahroun, 2019). For IoT devices to function effectively, they must be equipped with sensors that gather and transmit relevant data. These sensors come in diverse forms and are essential to the concept of DTs, where real-time sensor data allows a digital replica to monitor, analyze, and assess the condition of its physical counterpart (Wolfgang Kersten et al., 2019, pp.4–28).

2.5.3 Cloud Computing

Cloud computing is the delivery of on-demand services and resources over the internet by distributed computer networks such as data centers and servers (Jede and Teuteberg, 2015). Cloud computing involves hosted storage services over the internet, enabling scalable cloud-based storage solutions (Mohsen Attaran, 2017). For DTs, it provides both computational power and scalable cloud-based storage solutions. By using cloud infrastructure, DTs can manage and process large volumes of data, access necessary information from any location, and significantly reduce the computational time required for complex systems. This technology also helps overcome challenges related to storing and handling large datasets (Shu et al., 2015).

2.6 Value-To-Effort Matrix

The value to effort matrix is a decision-support tool used in root cause analysis to prioritize solutions after identifying the underlying problems. It helps determine which solutions offer the greatest impact with the least implementation effort. The matrix is structured as a two-dimensional diagram, with effort on the horizontal axis and impact on the vertical axis, divided into four quadrants as can be seen in Figure 6 which is based on work by the American Society for Quality (asq.org, n.d.). Options in the upper-left quadrant typically provide the best return on investment and should be prioritized, these are categorized as Quick Wins. Then there are Major projects, high impact and high effort; Fill-ins, low impact and effort; and Thankless Tasks, low impact and high effort. Proposed solutions are assessed and placed within the matrix according to these criteria. The matrix serves as a powerful tool for analyzing efforts compared to their impact and which projects to focus on.

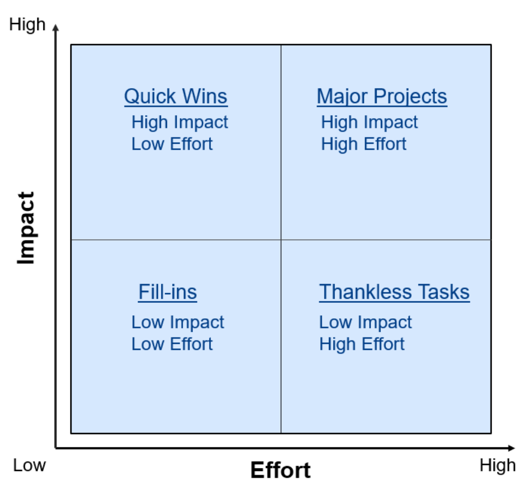

Figure 6: The impact vs effort matrix, based on the work by American Society for Quality

2.7 Conceptual Framework

To conclude the theoretical frame of reference, a conceptual framework is presented to compile the literature into a model for enhancing visibility (see Figure 7). Digital Twin is the technology that serves as foundation while supportive technolgoies, specifically IoT, AI, and Cloud Computing, facilitate the acquisition, processing, and scalability of data within the twin's architecture. Utilizing a DT, this platform implements the SDAR framework (Surveillance, Detection, Action, Response) by facilitating real-time monitoring and simulation-based "what-if" scenarios of the network. Together these can directly strengthen the pillars of visibility and overcome the functional silos. To bridge theory and implementation, the framework incorporates a Value-to-Effort matrix as a strategic filter. This allows for the evaluation of DT capabilities based on their operational impact relative to implementation effort, ensuring that the resulting roadmap is both technically feasible and strategically aligned.

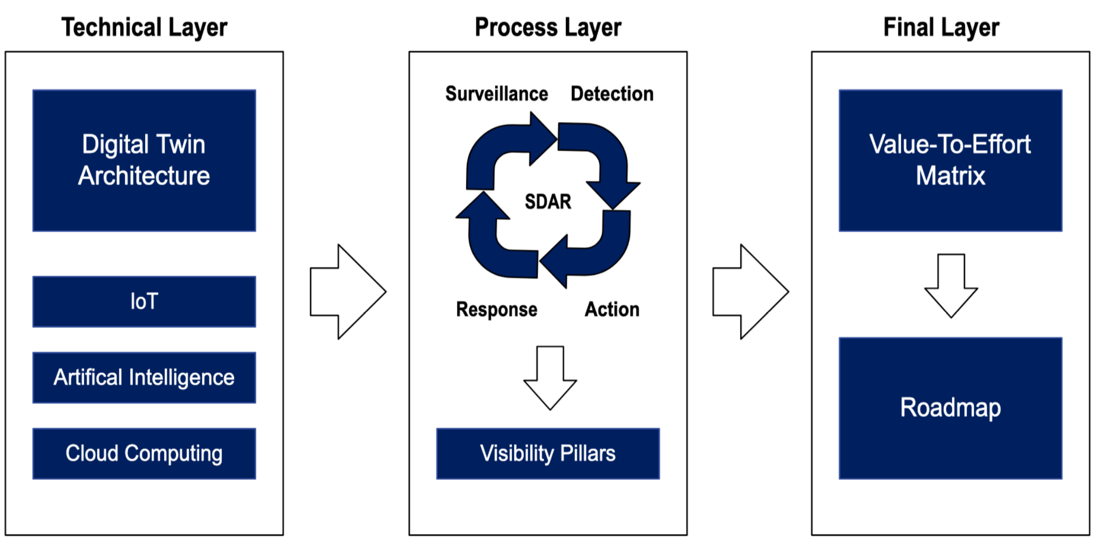

Figure 7: Conceptual Framework

3. METHODOLOGY

This chapter presents the research design and systematic process the to address the research questions are presented. It introduces the research philosophy and the approach that guided the study. Furthermore, it outlines the specific methodological choices, detailing the research strategy and the mixed-methods approach used for data collection and analysis. Finally, the chapter concludes by discussing the measures taken to ensure the study's trustworthiness and rigor, including credibility, transferability, dependability, and confirmability.

To explore how Digital Twins (DTs) can enable end-to-end visibility, improve decision-making in the spare parts network, and serve as a cross-functional platform that fosters collaborations and breaks down silos, this study is in its nature exploratory and follows a combined Eisenhardt research approach (Eisenhardt, 2021) with Saunders et al. (2019), performing theory building to gain insight before the case study. Additionally, it adopts a case study methodology in line with Yin's (2014) design and principles. The thesis will frequently move between empirical findings and theory to refine understanding and generate insights.

The unit of analysis will be digital twin technology applied to the current spare part supply chain network at The Company. Specifically, the functions within the spare parts network and the interconnectivity between them. The case will be bound within the timeframe of July 2025 to November 2025. Since the paper will look at the entire network, the outer boundaries will be the customers and the suppliers of the spare parts network; however, just the closest partners. Therefore, e.g., returns will be out of scope.

3.1 Research Onion

To structure the scientific research methodology, the framework of the "Research onion" introduced by Saunders et al. (2019) is applied. The research onion describes layers of complexity and of decisions involved in designing a research strategy, starting outermost with research philosophy and moving inward through research approach, methodological choice, research strategy, time horizons, and finally techniques for data collection and analysis. This layered model supports a systematic and transparent development of the research design. The research onion has been adopted for this thesis and is used as it provides a clear structure and explanation of the method. It is presented in Figure 8 and serves as the foundation for the methodological framework of this master thesis.

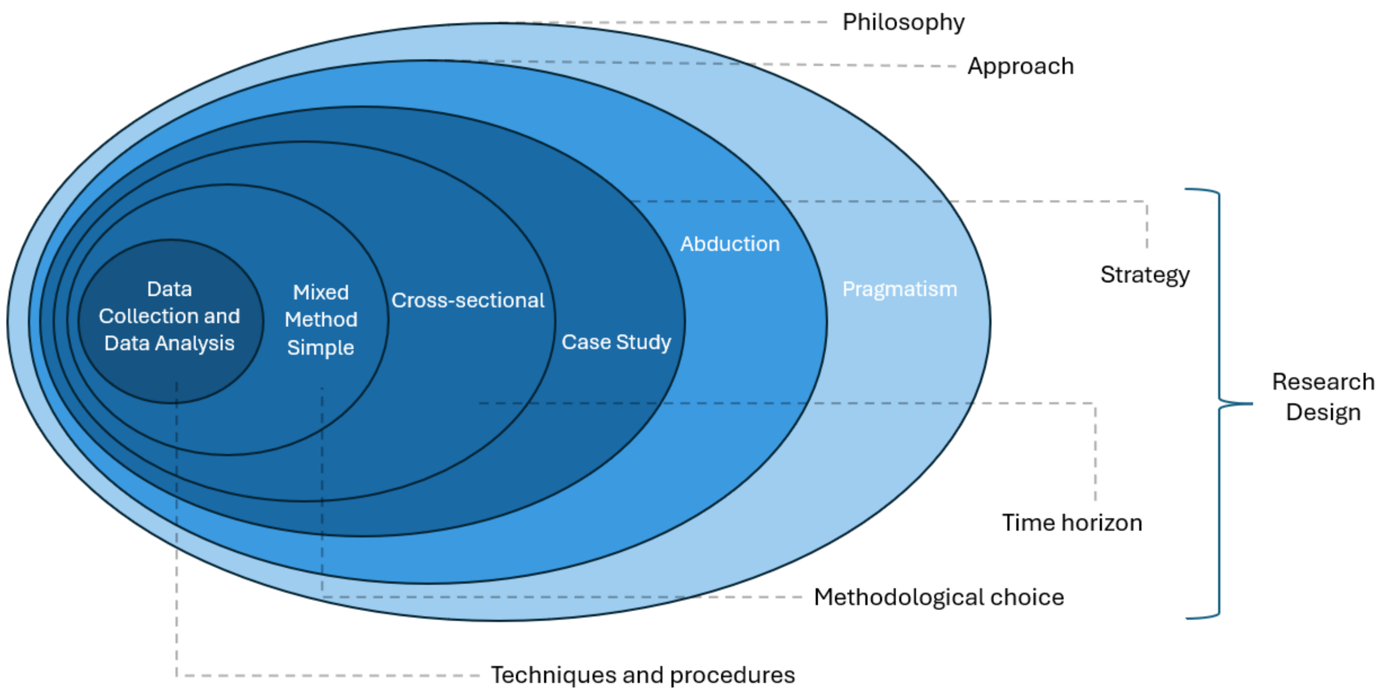

Figure 8: Modified version of "The Research Onion" (Saunders et al., 2019, page 130)

3.2 Research Philosophy

The outermost and first layer of the onion is research philosophy. Research philosophy relates to the development of knowledge in a particular field and contains important assumptions in which we view the world. These assumptions will in turn underpin the research strategy that will be established. There are three main ways of thinking regarding research philosophy and those are epistemology, ontology, and axiology. Epistemology is about what you consider valid knowledge and how you gather and share it. Ontology is about the theory that defines the nature of social phenomena as entities that can be recognized and incorporated within a system of knowledge. It concerns what we believe reality is, whether it exists independently or is socially constructed. Axiology concerns the role of your values and ethics in shaping your research choices and interpretations. (Saunders et al., 2019)

This master thesis follows a pragmatist philosophy, which is ontologically flexible. Pragmatism allows for more views of reality instead of committing to a single view and argues that the research question is the most important determinant. Different perspectives, such as positivism and interpretivism, are at our disposal to help collect and interpret data (Saunders et al., 2019). It is suitable for research that aims to solve real-world problems and generate practical insights and is particularly relevant since it recognizes that reality is multifaceted, and that both subjective and objective views are valuable. The master thesis will mostly gather qualitative data through interviews, including employee experience, perspective, and opinions. This data will be subjective. However, it will also gather quantitative data from, for example, existing ERP and WMS systems.

3.3 Research Approach

The research approach is the next layer. A research approach can be inductive, deductive or abductive. In an inductive approach, the first phase is to initially collect data, analyze it, and thereafter develop theories based on the data analysis. A deductive approach explores literature, develops hypotheses and theories, which in turn is tested using data. Lastly, an abductive approach begins by collecting data to explore a phenomenon and uncover underlying themes and patterns. These insights are then used to develop new theories or refine existing ones, which are then tested through further rounds of data collection and analysis (Saunders et al., 2019). Abductive approach is beneficial if the conclusion of a project is a practical solution or framework, rather than only describing a phenomenon. The purpose of this master thesis is to gain insights on DTs and explore how DTs potentially, subsequently be applied to the spare parts network's operations. An abductive approach is therefore the most relevant as it incorporates the literature review that will be done beforehand, aligning well with Eisenhardt research approach, and the data collection that will be performed iteratively with the analysis. Lastly, it is suitable since both quantitative and qualitative data are collected and analyzed.

3.4 Research Design Process

The next three layers of the research onion represent the research design. These layers are the research strategy, time horizon, and methodological research choices. The first layer regards the research strategy.

3.4.1 Research strategy

There are several strategies to choose from, however, it is important to choose the strategy that enables us to answer the research questions and meet the objectives. It is important to distinguish the label of the strategy from its contents (Saunders et al., 2019). The relevant strategies are experiment, survey, archival analysis, history, and case study (Yin, 2014). These can be seen in Table 3.

Table 3: Characteristics for different research methods (Yin, 2014, page 39)

Method	Form of Research Question	Requires Control of Behavioral Events?	Focuses on Contemporary Events?
Experiment	How, why?	Yes	Yes
Survey	Who, what, where, how many, how much?	No	Yes
Archival Analysis	Who, what, where, how many, how much?	No	Yes/No
History	How, why?	No	No
Case Study	How, why?	No	Yes

To investigate how Digital Twins (DTs) can improve end-to-end visibility, decision-making, and cross-functional collaboration within The Company's spare parts network, the chosen research strategy is a case study. This strategy is deemed appropriate because of the real-world complexity of the research context and the need to investigate the phenomenon in depth (Yin, 2014). The case study is bounded in time, scope (The Company's spare parts network), and focus (cross-functional collaboration, end-to-end visibility, and value drivers of DT). The selection of a case study strategy is further justified by the nature of the research questions, which all have the form "how", which is indicative of an exploratory study. The questions are best addressed through qualitative data collection, for example through interviews (Saunders et al., 2019). Moreover, the case study is conducted in a setting where control of behavioral events is limited, and the focus is on the current situation of the spare parts network at The Company and whether a DT is suitable, which suggests an exploratory approach. By conducting an exploratory approach, a better understanding of key issues such as visibility, communication, collaboration, and manual work processes can be attained. According to Yin (2014), case studies provide the necessary flexibility and depth required to explore the multifaceted nature of DT adoption in a global supply network. It aligns with the exploratory purpose of the thesis and supports the abductive reasoning process by continuous interplay between empirical findings and theoretical background and development.

The next critical step after choosing to conduct a case study is to define whether it is a single or multiple case design (Yin, 2014). Figure 9 presents the different designs and number of units to be analyzed. Depending on the nature of the study (e.g., number of units), there are several designs to choose from. The unit of analysis in this thesis is the current spare part network at The Company, more specifically, the specific functions within the network. Functions such as purchasing, outbound logistics, and sales, and the interconnectivity between them are sub-units to be analyzed. These sub-units are examined to understand the complexity of the spare parts network and how DTs may affect not only individual processes but also the coordination and information flow across the network. Therefore, as this thesis has one case but several units of analysis, an embedded single case approach was the preferred method. Exploring the sub-units is essential to answer the research questions and to identify where DT technology can support cross-functional collaboration, decision-making, and create value within the spare parts network. However, there are strengths and weaknesses to the single case study. For example, by choosing a single case study, the advantage is that it provides greatest depth but there might exist limits to the generalizability (transferability) and biases. (Voss, Tsikriktsis and Frohlich, 2002) Knowing the potential weaknesses is crucial to avoid encountering the weaknesses.

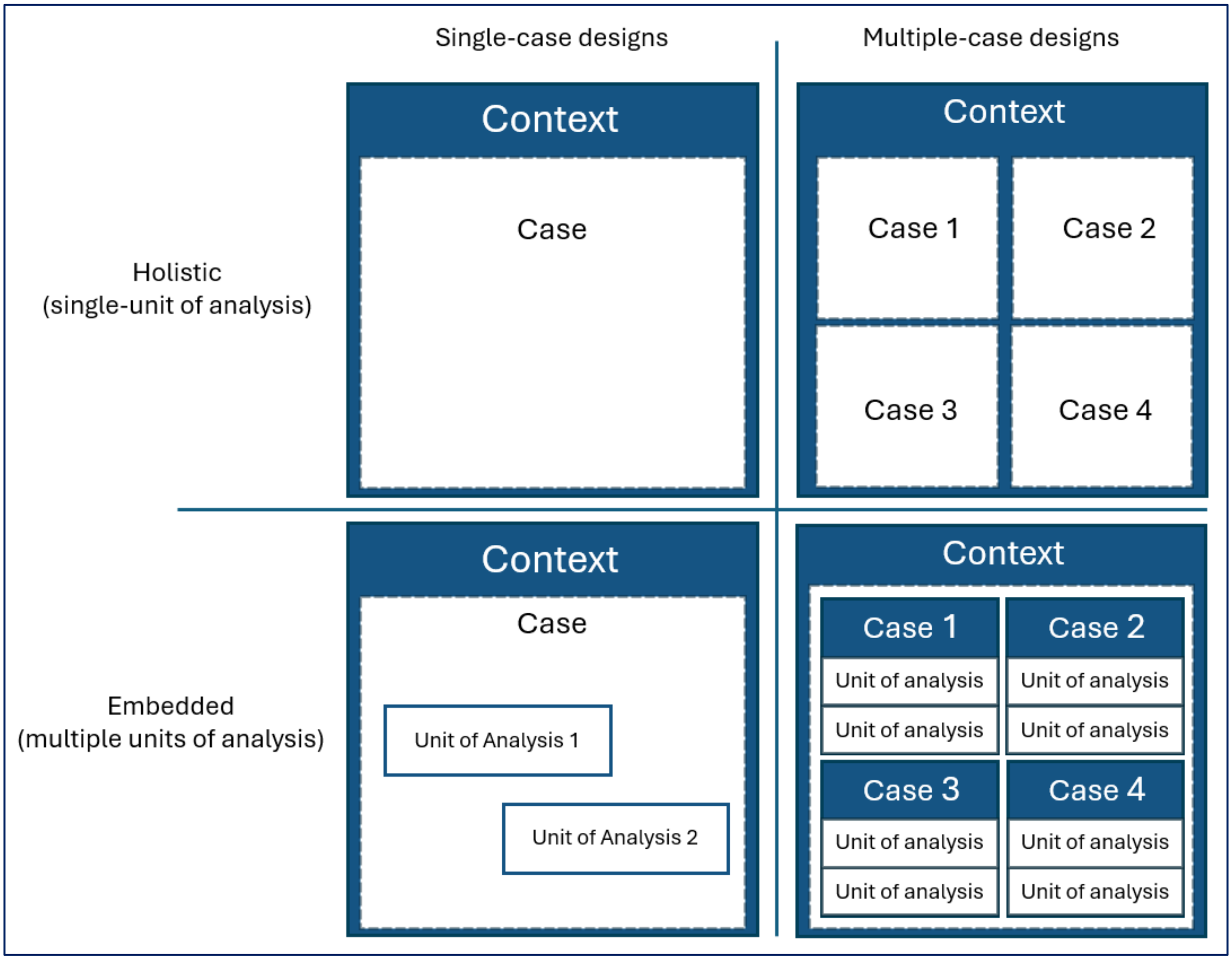

Figure 9: Designs for Case Studies (Yin, 2014)

3.4.2 Time Horizon

The next layer involves determining the time horizon of the research project. The time horizon can either be a "snapshot" of a particular phenomenon at a specific point in time, or a longitudinal approach resembling a diary composed of multiple snapshots over time. In the case study conducted at The Company, the research is not bound in time constraints and focuses on exploring the relationships between different functions within the network at this stage in time. Since the situation that is explored is not expected to change significantly as the thesis progresses, the time dimension is not a critical factor. Therefore, the study adopts a cross-sectional study, capturing a snapshot of the current state. Additionally, many case studies, such as this one, are typically based on interviews conducted over a short period, which further supports the relevance of a cross-sectional design. (Saunders et al., 2019)

3.4.3 Methodological Choice, Research Techniques and Procedures

After choosing the research strategy and establishing the time horizon, it is appropriate to choose what method should be used to perform data collection and data analysis. The choice is between quantitative research design or qualitative research design, or a combination of the two. The methods used can in turn be mono method, meaning that a single data collection technique is used. For example, semi-structured interviews for qualitative, and questionnaire for quantitative. The two research designs can furthermore use more than one data collection technique; this is known as a multi-method study. However, there is another branch of the multiple methods, and that is mixed methods research. This method involves combining the use of quantitative and qualitative data collection techniques. The different branches of methodological choices are displayed in Figure 10.

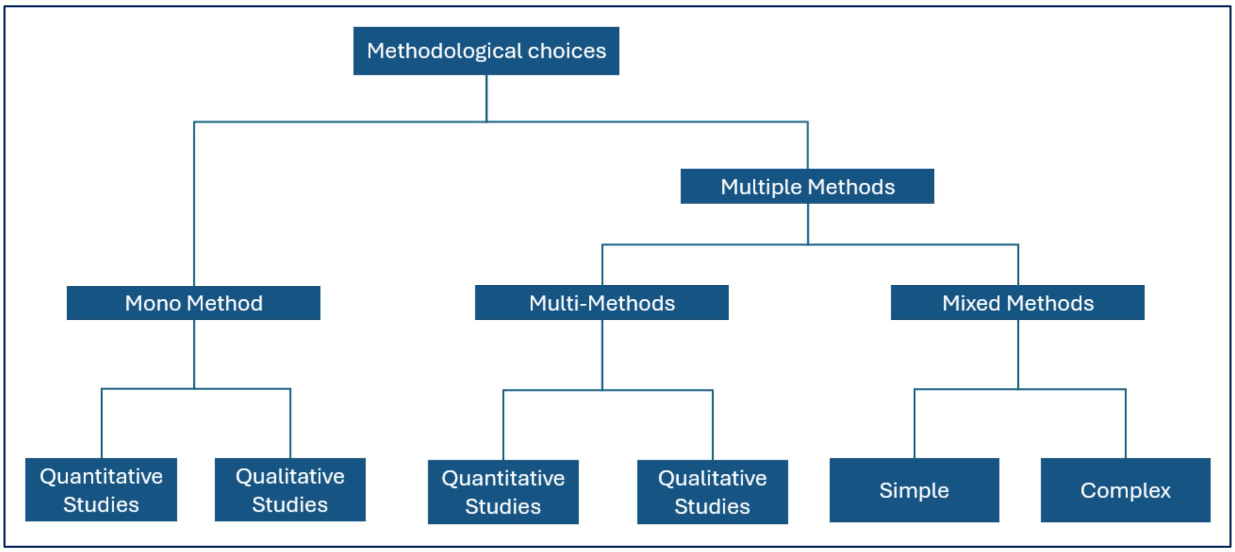

Figure 10: Methodological Choices (Saunders et al., 2019, page 176)

The thesis primary data will be through in-depth interviews and thematic analysis of them. This will be qualitative data. Alongside the interviews, there will be secondary data such as internal documentation from The Company's database, e.g., locations of spare parts or discrepancy reasons. This will be quantitative data. Therefore, multiple methods must be chosen. The mixed method is chosen because the research questions will be answered by qualitative data but with the help of quantitative data that in turn can be analyzed and then converted to fit the research questions. More specifically, a simple mixed method is chosen, also known as a concurrent mixed method. A concurrent mixed method approach involves the separate use of quantitative and qualitative methods, allowing an iterative process. This could provide more comprehensive and richer data than the mono method, and in a shorter time span (Saunders et al., 2019). Furthermore, by having a pragmatism philosophy along with an abductive approach, a mixed method is the best suited research choice. According to Saunders et al. (2019), when adopting a philosophical stance that combines a realist ontology with a subjectivist epistemology, for example critical realism, research may begin with qualitative methods to explore different individuals' perceptions. These insights can in turn be complemented by quantitative analysis of documentary data to identify potential underlying issues.

According to Tashakkori and Teddlie (2010), there are major advantages when choosing to use multiple methods within the same project. One advantage is that different methods can be used for different purposes. For example, having interviews with an exploratory approach, but gathering specific data in Power BI to collect descriptive or explanatory data. Another advantage is that it enables the possibility to triangulate the collected data. For example, complimenting semi-structured interviews with a survey. Additional advantages are broader diversity of views, help with interpretation, greater confidence in conclusions, etc. (Saunders et al., 2019)

3.5 Data Collection

3.5.1 Literature Review

Before conducting the case study and exploring empirical findings from interviews, a thorough, systematic literature review was performed. This to establish a theoretical foundation and what research has been previously published (Saunders et al., 2019). Research concerning visibility, Digital Twins (DTs), their technological enablers (e.g., IoT, AI, ML), etc. The literature review followed the method outlined by Rowley and Slack (2004), where the first step was to scan documents searching using online databases. Literature was found via the database Scopus (Accessed on 7^{th} July 2025 until 17^{th} of October 2025). Additional literature was also found via the Google Scholar database. The scanning was carried out with a search term that linked relevant subjects using Boolean logic, also known as search connectors. The search used the combination of keywords: (“Digital twin” AND (“Supply chain” OR “Logistics” OR “Visibility”), and the scientific journal papers published dates were limited to between 2018 and 2025. This was to avoid outdated scientific papers. This search term was deemed suitable based on the research questions and the objective of the master thesis. As a result, 764 studies were identified through the database search. Thereafter, the screening procedure continued by identifying relevant papers through checking titles and abstracts. Papers lacking a connection with the research questions or the objective are deemed as not relevant. The studies not relevant to the topic were excluded, bringing down the selection to 229 studies. Thereafter, a more thorough overview of the full-text view over the studies and excluding studies not deemed relevant and not mentioning the chosen keywords. At the end of the screening phase, 87 scientific papers remained. The next step was to determine the eligibility of the papers. Full-text checking was conducted and discussions about whether the papers were to be included or not. It was a requirement that the papers mentioned DTs or visibility in a supply chain context. Potentially relevant studies were narrowed down to 30. However, using forward- and backward-tracking methods, other papers from other databases (e.g., Google Scholar) were included in the final review (Kalaiarasan et al., 2022). These were included to complement the first review to fill any gaps in the literature. Thus, the final inclusion of studies was increased to 85. The identification and screening process of the literature can be seen in Figure 11.

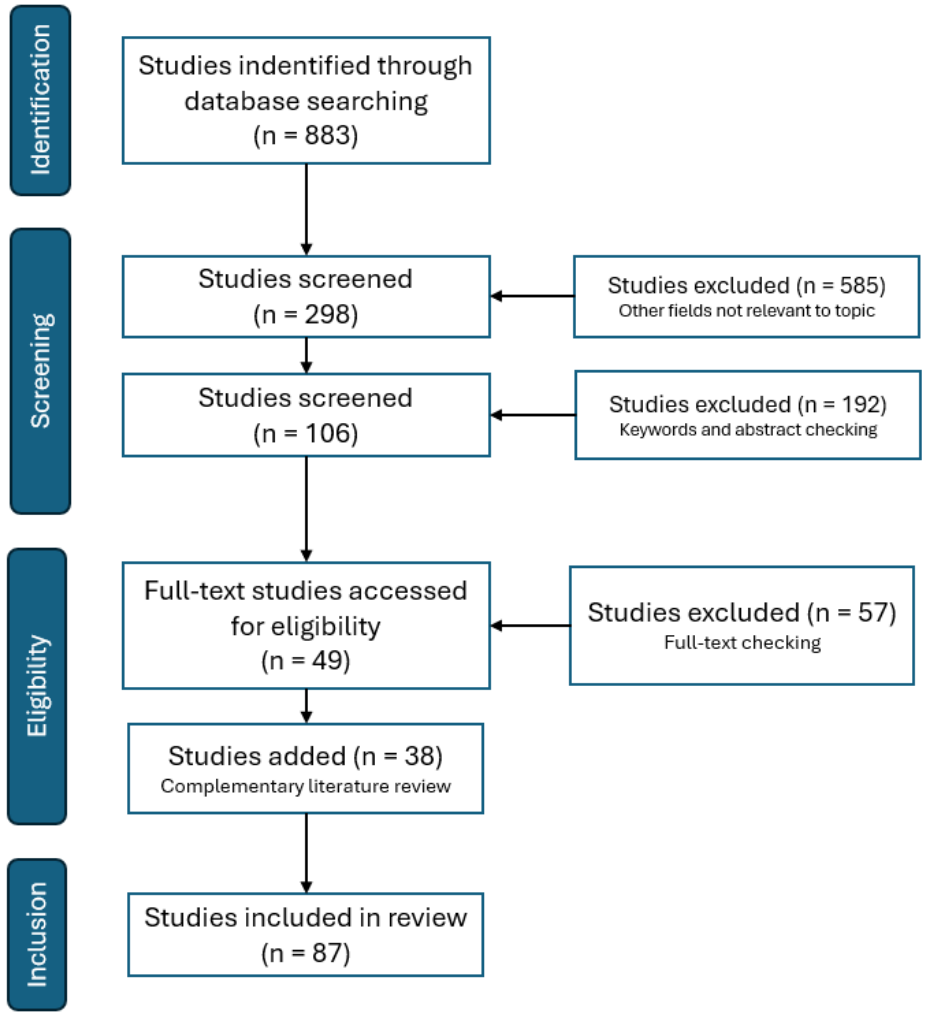

Figure 11: PRISMA flow, identification & filtering of studies via Scopus

The connection between the different concepts from the literature related to DT technology and its application in supply chain management context can be illustrated in Figure 12, generated using vosviewer. Together the concepts and clusters of keywords build an interconnected network. Central themes such as Digital Twin, Industry 4.0, Simulation, Internet of Things (IoT), Visibility, Artificial Intelligence, Resilience, and Decision-Making are among the core of this network. These relationships highlight that DTs are not standalone tools, but more of a solution combining real-time data, predictive modeling through simulation, and advanced systems to enable decision-making. Although, while some areas like "food supply chain" and "food supply" appear in the literature, they are less relevant to the scope of the thesis. This conceptual mapping was beneficial when defining the boundaries and determining whether a concept was out of scope. Understanding the interdependencies ensured a comprehensive review that was aligned with the objective of exploring a Command Centre can utilize DT technology to enhance visibility, resilience, supported decision-making, simulation of scenarios, and improve KPIs such as Service Level, Availability, Customer Experience, and Sales Order Backlog.

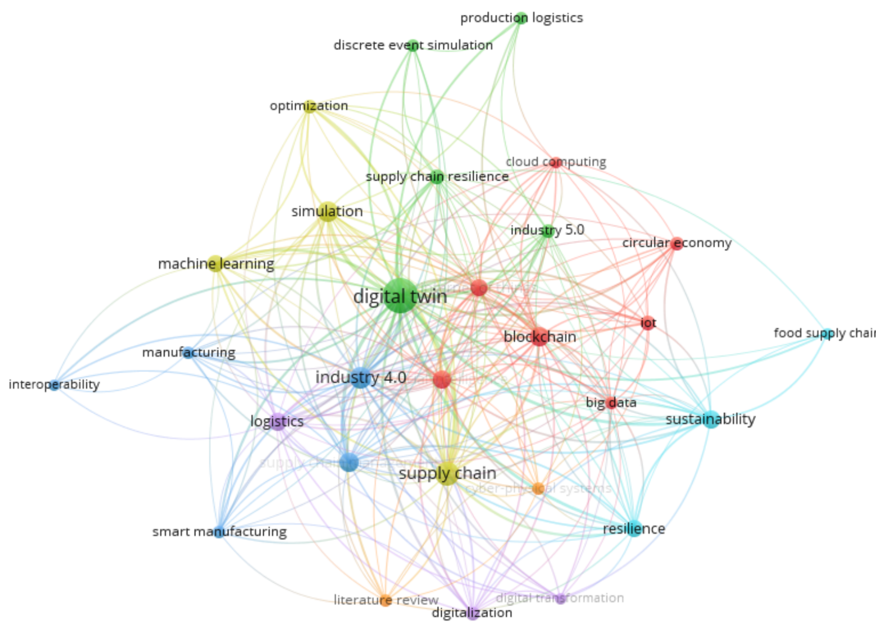

Figure 12: Visualization of keyword clusters

3.5.2 Interviews

This thesis will mainly use qualitative data collection through interviews to gain an in-depth understanding and primary data of the structure of the spare parts network, its operations, and challenges. Commonly, interviews can be divided into three different types: structured, semi-structured, and unstructured interviews (Saunders et al., 2019). These differ in the amount of strictness related to the questions asked. Structured interviews follow the order of an interview guide rigorously. Semi-structured interviews also have a pre-made interview guide, but as the interview progresses, the order of the questions can change, or follow-up questions that are not part of the interview guide can be asked. Lastly, unstructured interviews are interviews with no pre-made interview guide. In this thesis, the approach conducted to gather data was through semi-structured interviews. According to Saunders et al., (2019) a semi-structured interview is a combination of open-ended and closed questions. Saunders et al., (2019) also suggests that this approach offers flexibility in concentrating on topics of relevance and is particularly suited for qualitative research. The semi-structured format allowed for flexibility in the conversation, enabling interviewees to elaborate on areas which they find the most relevant. The method to perform semi-structured interviews was to create a general interview guide which was later adapted for each interview to fit their role but with general themes and questions remaining the same. The interview guide can be found in Appendix A1 and A2. Certain questions were considered more relevant to specific interviewees based on their roles. As a result, greater emphasis was placed on these questions, and not all questions from the interview guide were asked when they were deemed as less important. Lastly, the interview questions improved as interviews were conducted to ensure quality questions. Hence, the interview guide was adapted as interviews progressed.

The interviews were conducted either in-person or via video conferencing depending on the availability and the location of the participant. There were in total 20 interviews conducted, where the interviews lasted between 60-90 minutes, and where the Digitalization Manager and Director of Optimization participated multiple times. The selected interviewees consist of employees working in relevant functions at The Company and sampled to represent the functions within the spare parts network provided by the Digitalization Manager at The Company. Table 4 displays the interviewees with purpose of selecting participants and expected information to gain from it. See the extended table of interviewees in Appendix C. Additionally, to ensure comprehensive coverage of perspectives, the sampling process combined selection of participants with a snowballing approach. Initial participants were identified based on their roles and relevance to the research questions and the Command Centre project. Thereafter, during the process, some interviewees suggested additional colleagues whose expertise or responsibilities were more connected to the topics during the interviews. This iterative approach allowed the authors to capture insights from individuals who might otherwise have been overlooked, in turn providing more depth of the data collected. Additionally, an external Digital Twin Engineer was interviewed to gain valuable insights regarding DT technology. All the interviews were recorded and transcribed with the consent of the participants and additional notes were taken during the interviews to document the responses. The transcription was initially performed through Microsoft Teams inbuilt function and then scanned manually to ensure trustworthiness.

Table 4: Interviewees with purpose of the interview and expected information obtained from them

Interviewee	Role	Purpose
A	**Digital Twin Engineer**	Gather detailed insights into DT technology, its implementation process, data requirements, and integration with existing systems
B	**Digitalization Manager**	To obtain an overall understanding of the spare parts network operations, key challenges, and how DT technology aligns with the CC initiative
C	**World Class Manufacturing Manager**	Gain a deeper understanding of warehouse operations, performance metrics, and improvement initiatives
D	**Integrated Network Manager Americas**	To capture perspectives from Distribution Center (DC) employees, including operational challenges and perspective of current processes
E	**SR Business System Analyst**	Gain insights into operational challenges, system dependencies, and visibility issues within support processes.

F	**Supply Network Specialist**	Understand the role, connections with supplier management, prioritization strategies, and expectations for the CC
G	**Manager Global Operational Support & OT Security**	To clarify the role of Global Operational Support, its relationship with other functions, and security considerations in operational technology.
H	**Manager Planning & Inventory Optimization**	Assess expectations for the CC and its integration with the new planning system, including capabilities and limitations
I	**Global Planning & Data Expert (Group interview)**	To gather information on the new planning system's functionalities, its' overlaps with the CC, and capabilities
J	**Director of Optimisation**	To gather overview and expectations of the CC project. Gain insights regarding a potential detect and action system
K	**Replenishment Manager**	Understand operational workflows, replenishment challenges, and the connections between supplier management, supply network specialists, and planning process
L	**Integrated Network Manager APAC**	Capture the perspectives from APAC DC employees, focusing on operational challenges and improvement opportunities
M	**Supply Network Specialist**	Explore expectations for the CC, supplier management practices, KPI differences, overlaps with the new planning system even further
N	**Customer Service Excellence Manager**	To understand the customer perspective, customer service challenges, focusing on how the CC can enhance customer experience
O	**Distribution Center Manager Brazil**	To capture insights into the DC operations in Brazil and understand their challenges and perception
P	**Supply Optimisation Manager**	Perspective from supplier management on the spare parts network, leveraging the interviewee's prior experience in supplier management
Q	**Director of Planning & Quality**	Explore strategic requirements for the CC in supporting planning and quality processes within the spare parts supply network

R	**Sales Administration Manager**	To capture the sales perspective, operational challenges, and potential benefits of a CC.
S	**Sales Administration Manager**	To gain further perspectives from a sales administration and further explore how a CC could support its operations
T	**Logistics Solutions Manager**	Understand the transportation processes and the TMS (Transportation Management System) along with its capabilities and limitations. Additionally, gather information on data flows and data sources.

Additionally, there were biweekly meetings with the supervisor at The Company to address questions, resolve potential issues, and ensure that the research remained aligned with the defined scope and objectives. This iterative interaction with our supervisor helped strengthen the overall rigor and credibility of the study.

3.5.3 Survey

After all the interviews were conducted and the data was collected, the study was complemented by a structured survey distributed to the same participants. The purpose was to validate and prioritize the themes identified during the interviews, thereby enhancing the robustness of the findings through triangulation (Saunders et al., 2019). The survey along with answers from interviewees can be found in Appendix G and H respectively, there were 8 responses from the survey. It contained closed-ended questions assessing the perceived importance and feasibility of key value drivers for DT implementation. This sequential design reflects a multi-method approach, combining qualitative depth with quantitative confirmation to strengthen credibility and transferability. Inside the survey, the respondents were able to grade capabilities from not important to essential, rank data sources compared to each other, suggest things to detect and much more that can be seen in Appendix G.

3.5.4 Final Workshop

As a conclusion to the thesis the results from the thesis were presented to the management team of the spare parts network for the result to be validated. This was in the form of a one-hour session where the authors held a presentation with several injections of discussions.

3.6 Data Analysis

The data from the data collection was mainly qualitative, with some complementary quantitative to improve credibility. The analysis was conducted using thematic analysis as outlined by Braun and Clarke (2006), Saunders et al. (2019) and Miles, Huberman and Saldana (2014). The main goal of this analysis is to gather themes and analyze patterns from the collected data. It was chosen since it is flexible and suitable for identifying patterns while allowing for both descriptive and interpretative depth. The analysis was conducted primarily using an inductive or 'bottom up' approach (Braun and Clarke, 2006), meaning that themes were strongly linked to the data rather than being driven by a pre-determined coding frame. This ensured that the analysis remained grounded in the participants' experiences and perspectives. However, Braun and Clarke (2006) also mention that the process is not entirely theory-free, and that the interpretation of themes can be informed by the research questions and relevant literature. The framework of the thematic analysis consists of a procedure involving and can be seen in Figure 13.

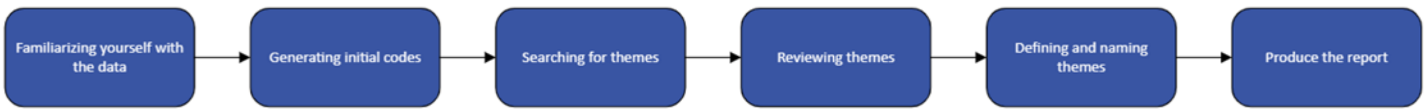

Figure 13: The six phases of thematic analysis (Braun and Clarke, 2006)

The first phase is *familiarization with the data*, which includes immersing yourself in the data, transcribing the interviews and reading the transcripts multiple times to gain a deep understanding of the content. This familiarization helps to build a holistic understanding and view of the context. This guides the first coding process, where initial ideas and observations are noted, forming a foundation.

The second phase is *generating initial codes*. Here, meaningful segments of text are identified and labelled. Each unit, ranging from a word to a sentence to a paragraph, can be labelled with a code that represents the content. Coding was inclusive which allowed units to be assigned multiple codes where relevant.

The third phase is *searching for themes*, where related codes were grouped into potential themes and in turn sub-themes. This phase is important as individual code is transferred to themes and thereafter used to identify broader patterns that capture significant data related to the research questions.

The fourth phase consists of *reviewing themes*, which includes two levels of reviewing and refining. First step is to review the themes and determine if they form a coherent pattern. If the themes do not fit, it should be decided if the theme is problematic by itself or if some of the data extracts do not fit within the theme. Then, a new theme needs to be created for the extracts that do not fit, or to discard them. Once satisfied with the themes, the second step can be initiated. Here the validity of the themes is evaluated to see if the themes reflect the meaning in the data set. The goal is to build a map that reflects the complexity of the spare parts network and the potential impact of DTs on key topics such as visibility, cross-collaboration, and decision-making.

The fifth phase is for *defining and naming themes*. At this point, the themes are defined and refined and will be presented in the analysis. The definition of the themes incorporates the essence of each theme and determines its scope. It is important to define what the themes are and what they are not.

The sixth and final phase involved is *producing the report*, where themes are integrated into a narrative ("story") that aligns with the research objective. Representative quotes are selected to display each theme, ensuring credibility and transparency. This iterative approach provides a solid foundation for interpreting the qualitative data and developing the conceptual framework.

At the same time as the qualitative data was collected and analyzed, quantitative data from internal archives was also examined. To analyze this quantitative, a Pareto principal analysis was applied. This principle, often termed as the 80/20 rule, was introduced by Vilfredo Pareto to demonstrate that eighty percent of Italy's wealth was distributed among twenty percent of the total population (Powell and Sammut-Bonnici, 2014). The principle identifies that a minority of inputs typically generate the majority of results. In this study, the analysis is used to isolate the 'vital few' causes of network issues that account for most observed issues.

To conclude the analysis, a prioritization through a Value-to-Effort matrix was conducted to bridge the gap between identified network challenges and actionable Digital Twin solutions. This process involved evaluating each proposed capability along two primary dimensions, value and effort. Value defined as the potential to improve decision-making, enhance visibility, and dissolve silos and Effort measured by the expected difficulty required for implementation, considering data integration, system development, and organizational readiness. The analysis was grounded in the study's theoretical framework, utilizing the four pillars of visibility and the SDAR framework to ensure that each solution directly addressed the structural gaps identified during the empirical phase. In instances where stakeholders were conflicted regarding rankings of solutions, it was resolved through a consensus-seeking approach during the final validation workshop. This methodological choice ensured that the final positioning in the matrix reflected a balanced organizational priority and technical reality, rather than the isolated needs of a single functional silo.

3.7 Research Process Framework

To conclude the theoretical frame of reference, a conceptual framework declaring how the literature review together with empirical findings will be used to answer the research questions and what steps to take is presented. The framework serves as a guide for linking theoretical insights with practical observations, ensuring that the analysis aligns with the objective of the master thesis. It combines three key components: concepts derived from literature regarding relevant subjects, empirical findings from interviews that reveal, for example, challenges within the spare part supply network, and an analysis that iteratively connects theory and practice. As illustrated in Figure 14, the literature review and empirical findings are inputs into the analytical process, which in turn produce sufficient insights to answer the research questions. The conceptual framework clarifies the flow of the research and enhances transparency, ensuring that conclusions are grounded both in established research along with the findings from The Company.

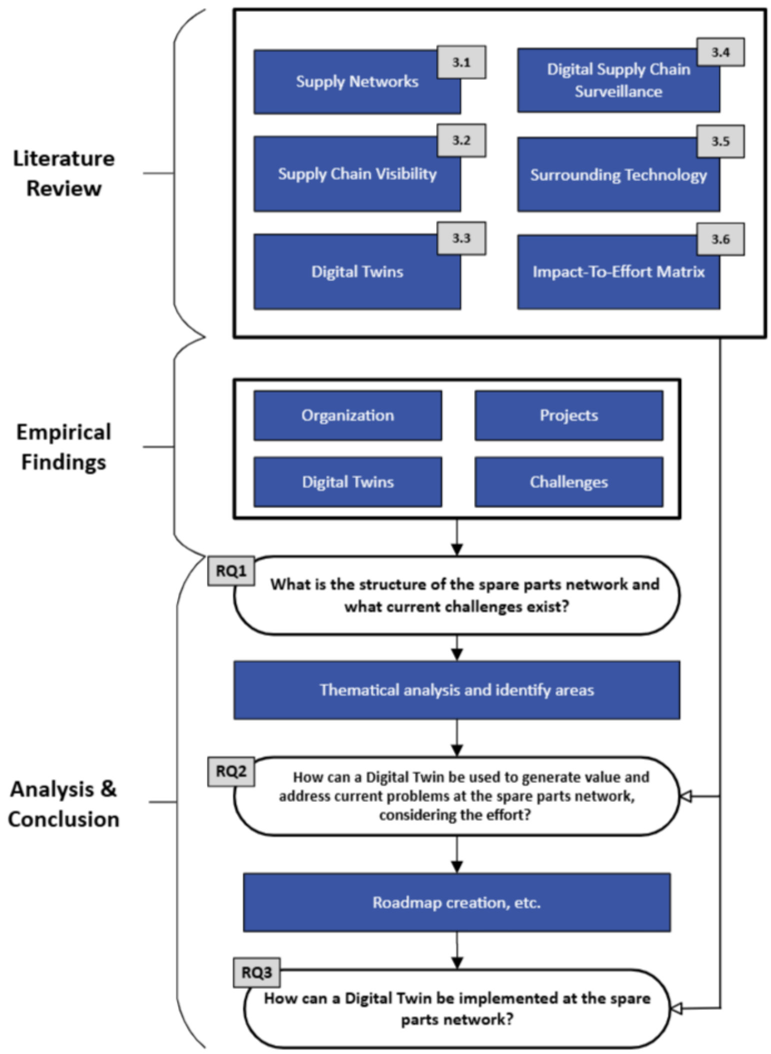

Figure 14: Research Process Framework

3.8 Trustworthiness

To ensure the credibility of the study, it is crucial to ensure trustworthiness. Traditionally, the criteria for research quality were presented by Yin (2014) and consists of internal validity, external validity, reliability, and objectivity. These are especially relevant when conducting case study research. However, instead of choosing the conventional criteria, Halldórsson and Aastrup (2002) argue that realism in various forms dominates logistics thinking and therefore should other naturalistic criteria reflecting the realism be applied instead. These corresponding qualities are credibility, transferability, dependability, and confirmability (Halldórsson and Aastrup, 2002). Furthermore, Halldórsson and Aastrup further argue that trustworthiness provides better guidance when evaluating research quality. For example, when reflecting reality and perceptions, and providing a moral view on quality. As this thesis is grounded in qualitative interviews and case study methodology, with supporting quantitative data, these criteria are relevant, align with the pragmatist philosophy, will guide the research process, and help ensure trustworthiness. The measures taken for each criteria to ensure research rigor and high trustworthiness are presented in Table 5 along with the four criteria mentioned below.

3.8.1 Credibility

The first criterion of trustworthiness is credibility. Credibility refers to the extent to which the findings accurately reflect participants' perspectives and is parallel to the conventional notion of internal validity. According to Halldórsson and Aastrup (2002), the respondents' perceptions of reality are based on their context, therefore there is no single objective reality. To strengthen the credibility for this thesis, interview summaries were shared with participants after corresponding interview for validation, allowing them to confirm or correct any of the interpretations concluded. This ensured that the material gathered from the interview was presented as the interviewee intended it. Additionally, the final placement of capabilities within the Value-to-Effort matrix was validated through a dedicated workshop with the spare parts network's management team. This collaborative assessment served as the critical link between the iterative thematic analysis and the final development of the implementation roadmap.

3.8.2 Transferability

Transferability is the second criterion of trustworthiness, and its conventional notion is external validity. Transferability concerns the applicability of findings to other contexts and the extent the findings can make general claims about the world, also described generally as a measure for generalizability (Halldórsson and Aastrup, 2002). However, unlike external validity, transferability depends on the degree of similarity between one context and other potential application settings. Just because knowledge is acquired in one context, it does not exclude it from being relevant in another. Therefore, it is crucial to develop clear descriptions of contexts gathered from interviews, the organizational environment, the roles of participants, etc. Transability can be strengthened further with the use of triangulation.

3.8.3 Dependability

Dependability is the next criterion, and its conventional notion is reliability. Reliability is seen as a precondition for validity and is attained through replicability of research results. Reliability is traditionally seen as quite sensitive to changes to e.g. methodology, while dependability is viewed as more flexible. Dependability, in contrast to reliability, addresses the consistency, stability, and transparency of the research process over time. Rather than focusing on the replicability of research results, it introduces and emphasizes trackability. This thesis distinctly outlines its research approach and strategy, data collection procedures, and analytical process in detail. This is to communicate the logic of process and method decisions and enhance the dependability of the study. (Halldórsson and Aastrup, 2002)

3.8.4 Confirmability

The last criterion of trustworthiness is confirmability and is parallel to the conventional view on objectivity. Objectivity has the goal of findings representing the results and does not take the researcher's biases into account. However, Halldórsson and Aastrup (2002) argue that complete neutrality is unattainable. They further state that to support confirmability, all data and findings must be linked to specific data sources and possible to trace. This thesis used an interview guide that is presented in Appendix A and Appendix B, and data gathered from interviews and used for conclusions are clearly presented. Follow-up meetings and interviews with the supervisor at The Company were conducted throughout the project to validate emerging insights, and a final validation interview was held near the end of the project to confirm the accuracy of the conclusions and interpretations.

Table 5: Measures for each criteria

Criteria	Measures
Credibility	• Semi-structured interviews recorded and transcribed with participant consent. • Interview summaries shared with participants for validation. • Deep research before interviews to understand participants' perspectives better. • Iterative refinement of interview guide to improve question quality. • Quotations used were sent out to participants for confirmation • Questionnaires sent out on the form of surveys to complement the primary data collection. • Regular validation meetings with The Company supervisor and academic supervisor. • Thematic analysis used for systematic coding.
Transferability	• Rich description of The Company's spare parts network, its structure, and operational context. • Detailed explanation of roles, processes, and ongoing projects. • Clear presentation of case boundaries and scope. • Conceptual framework linking findings to broader literature.
Dependability	• Transparent documentation of research design using Saunders' Research Onion. • Explanation of research philosophy, approach, and strategy. • Interview guide and data collection protocols included in Appendix. • Mixed-method approach explained and justified. • Iterative data analysis process documented.
Confirmability	• Findings traceable to specific data sources (quotes, documents, literature). • Use of interview guide to ensure consistency. • Audit trail maintained through notes, recording, transcripts, and coding records. • Regular feedback loops with supervisors and final validation interview. • Reflexivity acknowledged and documented.

4. EMPIRICAL FINDINGS

In this chapter, the thesis purpose and the objective of implementing a Surveillance Digital Twin within The Company's spare parts network, are reiterated. It provides an overview of the spare parts network's structure, operations, and current processes. Thereafter, ongoing projects within the spare parts network that align with the Surveillance DT initiative will then be presented. The chapter also establishes operational challenges and pain points identified through interviews and surveys. Finally, the chapter concludes by presenting the desired capabilities for the ongoing project as expressed by interviewees, which offers insights into expectations and functional requirements for a successful Digital Twin.

4.1 Overview of the Case Context

4.1.1 Structure & Functions of the Spare Parts Network

There is a network for The Company's machines, and spare parts for said machines in factories around the world. The service department is structured with the aim of providing world-class service to the customers of The Company. The mission of the spare part network is to provide unique and superior customer experience by being the undisputed industry leader in supply network. The network supports customers across the globe with their orders for spare parts, consumables, and other products included in the services portfolio. The network consists of global suppliers and customers, four Sales Administration Centers (SACs), eight Distribution Centers (DCs) and three Maintenance Unit Workshops (MUs). To deliver parts from supplier to customer, the network is composed of several key functions with distinct responsibilities but interdependent processes. The functions along with description and responsibilities are presented in Table 6 while the visualization of the interviewees along with their functions and connections are displayed in Figure 15.

Table 6: Functions in the spare parts network and their description (Digitalization Manager, 2025)

Function	Description
Planning	Responsible for planning and securing global availability of spare parts and optimizing stock turnover by deciding what and when to procure. The function consists of several roles such as Global Planning & Data Experts, Supply Network Specialists, Replenishment, and more. The function is crucial to secure delivery quality to DC's, customers, and needed to achieve efficient and effective supplier delivery performance.
Quality	Quality teams across the globe ensure that quality of the spare parts are according to specifications and meet the right quality standard. Monitor and enhance the accuracy of inbound handling on discrepancies. Also manages ISO certification for the spare parts network.
Operations	Manages physical handling across the network, including inbound, warehousing, and outbound activities to ensure efficient parts distribution. It ensures that parts are received, stored, and dispatched efficiently and accurately. It is also responsible for the MU workshops, which assemble

	complete packages of spare parts tailored to specific machines. These packages are sent as kits ready to install.
Transport & Logistics	Responsible for the global movement of parts, including activities such as carrier coordination, customs handling, and last-mile delivery. It consists of roles that manage both tactical transport planning and operational execution, e.g. urgent shipments. The function is crucial for maintaining high service levels and minimizing delays.
Sales Administration	Serves as the administrative interface for customers, managing order entry, issues in master data, pricing updates, documentation, and customer inquiries. It escalates the issues customers are experiencing and is described as the "ears and voice of the customer", playing a critical role in ensuring customer satisfaction.
Customer Excellence	Dedicated to capturing and analyzing customer feedback through surveys and complains to drive continuous improvement. It translates customer insights into actionable changes to ensure the network meets evolving needs and expectations.
Supply Network Optimization	The function is responsible for continuously improving, and optimizing, processes and tools across the network. Its objective is to increase agility, reliability, and performance of the supply network with a strong focus on global transportation, project portfolio, new assortment integration, automation and digitalization.

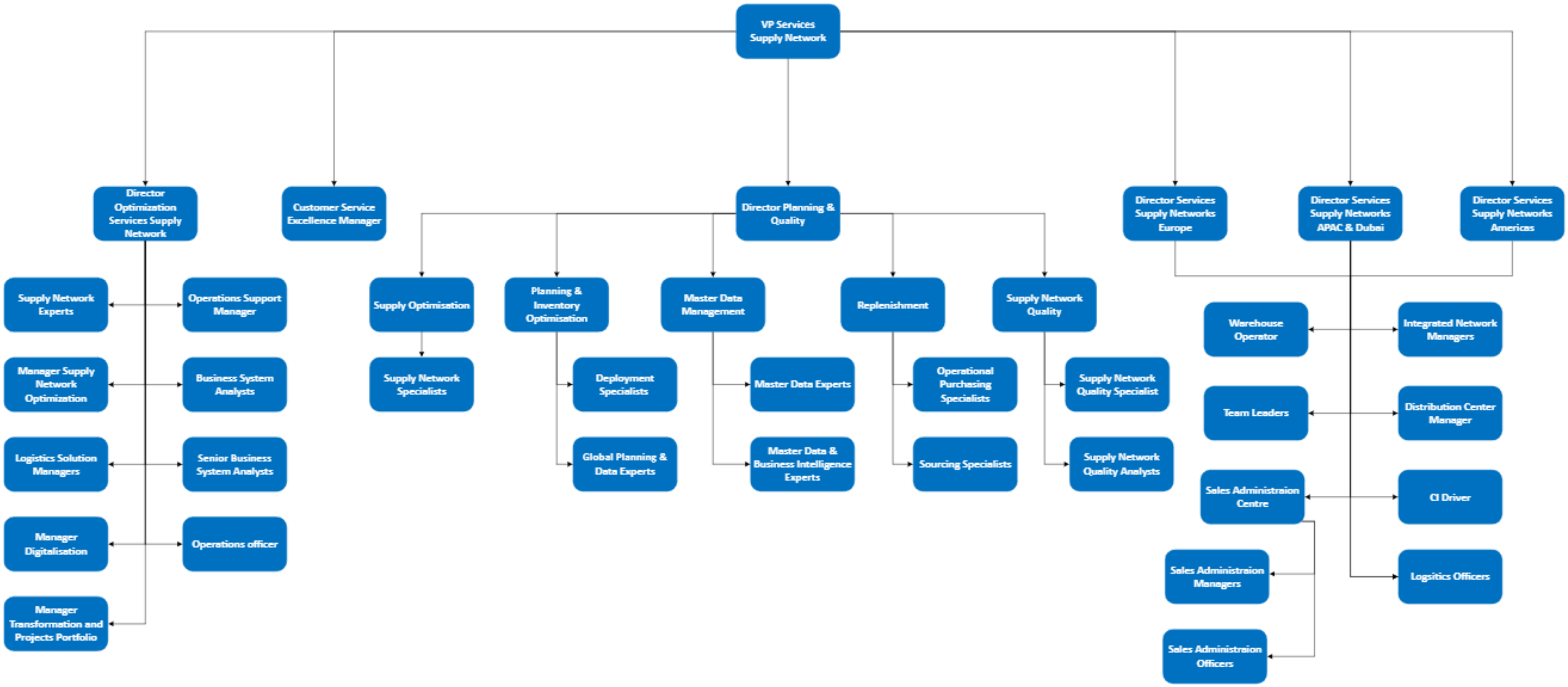

Figure 15: Overview of the roles in the spare parts network and their relation to each other

4.1.2 Order-To-Delivery Timeline

The Order-To-Delivery flow of spare parts and key activities involved in delivering them to customers is illustrated in Figure 16. The process of a part being delivered to the customer begins with the customer placing a Purchase Order (PO) for the part. This is sent to the Market Company of the region where the customer is located. The Market Company creates a Sales Order for the spare part and sends out a new PO to the Regional DC if the part is in stock. If there is no part in stock at the regional DC, the PO is sent to the Main DC in Europe. At the DC, the goods are received (GR), picked and packed, and placed in the inventory. Once prepared, the shipment enters the first mile of transportation and proceeds through customs clearance. After customs, the part moves into the final mile and is delivered to the customers.

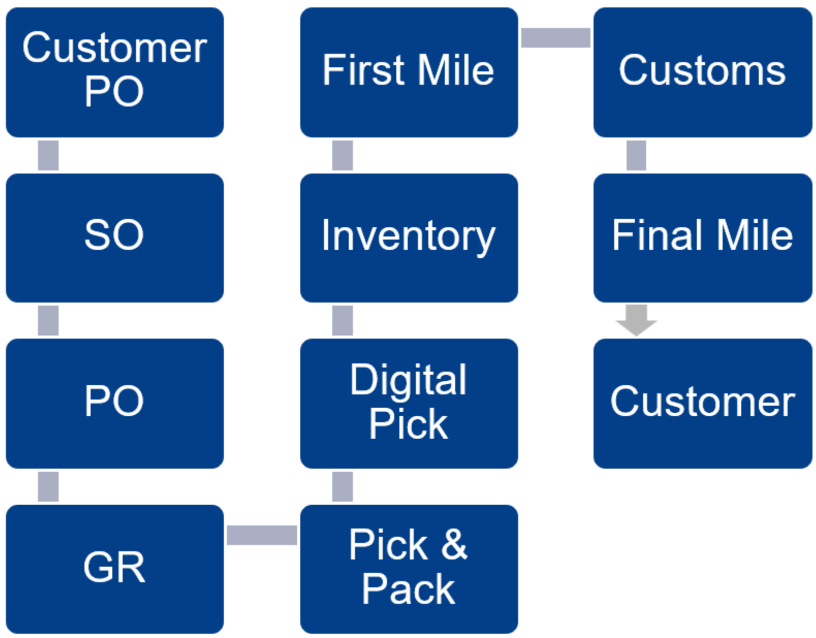

Figure 16: General flow of spare parts and activities across the chain

Establishing this flow is important for mapping the supply chain visually and identifying its key nodes such as suppliers, DCs, and customers. By mapping each node and connecting the corresponding data streams, The Company ensures accurate integration between physical and digital layers, a step that has already been accomplished at The Company.

4.2 Ongoing initiatives related to Digital Twins

The spare parts network of The Company is on a transformation journey with the aim of creating a global network of DCs. Therefore, the two current main initiatives that will enable the transformation to a global network are the Command Centre (CC) project and the implementation of the new planning system. The current planning system is outdated and does not support the network ambition in an efficient way. The Company aims to optimize planning processes and increase flexibility in a multi-dimensional environment. The new system should allow for dual source and flexible routes. The features in the system should use standard processes and limited adaptation to allow easy update to latest version. The master's thesis is mainly focused on the CC as it will be based on DT technology. However, it is equally important to establish the new planning system that is implemented alongside it, as they are intertwined and that both systems together will enable the transformation toward a more predictive, integrated, and data-driven spare parts network.

4.2.1 Command Centre

The Command Centre (CC) is one of the cornerstone projects in the spare parts network transformation but is currently in early development. It is designed to be a centralized platform and span over the entire network. It will act as an operational nerve center, integrating data from multiple systems to enable faster, more informed decisions. This initiative is an investment in a modern platform to enable for example End-to-End visibility, increase resilience through better distribution planning, and inventory balancing. A DT can help unlock these capabilities. The capabilities to best serve the customers.

When creating a DT of a supply chain, the first step usually starts with implementing a control tower. This is the foundation of the DT, where real-time data is compiled and visualized through dashboards to give an overview of the network's current state (IBM, 2021c). Meanwhile, a DT provides the current visibility, along with simulation capabilities of what could happen in the future. On top of that, machine learning and generative AI modules can be applied to optimize performance. In this context, the CC can be seen as the heart of the DT, with optimization techniques functioning as the brain and the connection layer acting as the sensory system, the eyes and ears of the supply chain. The Digitalization Manager expresses that by connecting all relevant systems within the network, the aim is to create unified visibility, enabling quicker decisions, proactive deviation signaling, and improved responsiveness. Key goals of the project include full and quick traceability, improved response time to customer requests, proactive deviation alerts for supplier delays and transport disruptions, and faster actions through decision support.

Interview insights reinforce the projects' strategic importance. The director of Planning & Quality at the spare parts network describes the CC as "*a key enabler for a broader transformation toward resilience, flexibility, and a network supply chain. Frequent supplier confirmation slippages need impact analysis and reallocation options across sites, and these should be provided in the Command Centre.*"

4.2.2 Planning Project

The Planning Project is a parallel initiative to the Command Centre (CC) but also intertwined since both projects share the same software platform and data foundation. However, their scopes differ as the planning project is connected to the implementation of the new planning system and focuses on enhancing tactical and strategic planning capabilities. It emphasizes a long-term scope while the CC targets operational execution and visibility. As one of the Global planning & data experts noted: "It is the same software, interface, and everything", highlighting the shared technological base. The Planning project introduces simulation capabilities that allow users to model any potential network changes without impacting live operations. For example, site shutdowns, safety stock adjustments, and changing sourcing strategies. This approach enables safe experimentation, followed by implementation of approved scenarios. This is the aim and wish for the planning system, as described by the Global Planning & Data Experts*: "Upload the scenario (...), see what happens without implementing anything [and] then you push a button, and it implements".*

The project is seen as foundational yet complex, with the Manager for Planning & Inventory Optimization likening it to "open-heart surgery." Its success is critical to achieving the network ambition of flexible routing and dual sourcing since the current planning system is considered outdated and insufficient to support these goals efficiently. Today, mostly historical data is used for planning. However, the aspiration is to inject maintenance ("service events") data, especially for contracted customers, to predict needs. Additionally, in the ideal future, the project aims to incorporate machine learning and install base data to position stock proactively and enable auto-replenishment before orders are placed. This capability would significantly enhance responsiveness and reduce lead times.

In summary, the Planning Project complements the CC by providing the strategic foresight and simulation tools necessary to align operational execution with long-term network goals. Together, they form the backbone of a more resilient, data-driver supply network.

4.2.3 Spare Parts Network Transformation

The Command Centre, the new planning system and a new customer relations management system will together form the foundation for transforming the spare parts current state into a fully integrated, resilient, digital, and customer-centric supply network. They are essential to shift operations from a hub-centric model, with Lund being the main node, to a network-based structure. This transformation seeks to reduce lead times by enabling source-to-market flows, increase resilience through multi-sourcing and dynamic routing, and lastly to support global customer needs more effectively and align with The Company's mission. The mission to provide unique and superior customer experience and position itself as the undisputed industry leader in supply network excellence. This transformation is not only about efficiency, but it also establishes a proactive, data-driven approach that aligns operational execution with long-term strategic objectives. All to achieve End-to-End visibility and transparency. As the Planning & Quality Director expressed, "Transparency is the foundation for transformation, without it we cannot move forward".

4.3 Challenges at the Spare Parts Network

One of the main pillars to address where DT capabilities can help is to identify all relevant challenges at the spare parts network. Table 7 presents an overview of challenges that the interviewees mentioned during the interviews. The external Digital Twin Engineer addressed challenges related to DTs within the industry, while the rest of the interviewees are employed at The Company and addressed challenges they perceive and experience within the spare parts network. Following Table 7, relevant and commonly brought up challenges are highlighted along with quotes.

Table 7: Interviewees, the topics discussed along with challenges

Role	Challenges
Digital Twin Engineer	• Cybersecurity • Live data collection and messy historical data. Requires pipeline, APIs, and quality checks (missing/nulls, normalization) • Real-time communication • Security & access control, important to implement certificates and signatures/keys to protect sensitive data and control streaming connections
Digitalization Manager	• Data quality and completeness (ensuring reliable and timely data across systems). • Functions working in siloes • Lack of end-to-end visibility for employees and customers • Lack of cross-functional collaboration • Ensuring value creation from the Command Centre (CC) and justify its case
World Class Manufacturing Manager	• Outbound is identified as the constraint. • Sense that inbound ordering sometimes exceeds needs, creating dead stock and storage pressure • Siloed thinking • Inefficiencies in inventory planning
Integrated Network Manager Americas	• Manual data collection and lack of system integration, tariffs • Silos caused by carrier data dependencies and uneven information updates across countries. Heavy reliance on the local carriers with limited digital capabilities • Limited visibility of transport and supplier delays • Disconnected systems (ECC, WMS, TMS, etc.) hinder end-to-end tracking • Lacking product classification and origin data affect customs clearance times, in turn increasing delays • Limited capability to simulate constraints (e.g. air capacity) and quantify cost/lead-time impacts quickly on decisions • Forecasting issues where planning is history-heavy and manual. It underuses installed base, running hours, and maintenance data for proactive forecasting • Tariffs and stricter classification increased customs release times and forced network re-routing, affecting service and cost
SR Business System Analyst	• Customers often rely on support teams to locate orders and shipments • Not all disruptions are reflected in metrics
Supply Network Specialist	• Poor data quality and lead time variability (some suppliers exceeding 200 days) • Limited supplier contact (especially with smaller vendors) • System limitations (current tools lack simulation capabilities and real-time responsiveness)

	• Crisis readiness (difficult to predict and handling supplier shocks). Cyclical macro swings plus supplier-specific shocks create extreme lead-time spikes and shortages • Adding new suppliers is hampered by quality/validation at scale. They cannot compromise quality even under pressure
Manager Global Operational Support & OT Security	• Visibility gaps, difficulty knowing what information is missing ("hard to know what you don't see"), lack of overview of ongoing projects • Cybersecurity risks, risks of misinformation ("better to have no data than wrong data") • KPI misalignment, KPIs should be actionable. The current ones sometimes measure outcomes that teams cannot influence directly • Zero-sum workload reality • Reliance on personal networks instead of structured networks
Manager Planning & Inventory Optimization	• Data integration gaps. There is no automatic link between maintenance events and planning, manual input required for new machines and predictive maintenance data. • Alert limitations, current tools lack proactive alerts, no system-level notifications for trends like increasing transport times or supplier delays. • Organizational ambiguity, unclear who should act on specific issues, planning team often takes on responsibilities beyond their scope. • Today the demand forecasting is mostly historical data.
Global Planning & Data Expert (Group interview)	• Systems are outdated (especially lacking real-time simulation) • Gaps in End-to-End tracking (e.g. limited connection to logistics providers TMS) • Need for pegging logic
Director of Optimization	• System fragmentation where multiple systems (ECC, EWM, etc.) operate independently with no clear ownership of handovers. • Silo gaps where teams and systems operate in silos with unclear ownership of the "in-between" handoffs, creating friction and blame loops • Lack of visibility across segments leads to inefficiencies and missed shipments. • Multiple systems/modules don't fully interoperate; some "live their own life," causing stuck orders and invisible backlogs technical issues (System landscape) • Master Data issues - missing or incorrect article and customer master data (e.g. HS codes, C) cause compliance issues and shipment delays. • Manual detection & escalation – detection of issues is reactive and often too late. • There is no structured process for prioritizing or resolving disruptions. • Capacity planning gaps with no real-time monitoring of picking capacity vs. Order volume, leading to risk of underperformance due to lack of proactive staffing or rerouting
Replenishment Manager	• High volumes of PO lines • Supplier reliability issues • Silo processes

	• Overload of urgent market requests • Priority issues • Capacity issues (we order a lot, but supplier does not have the full capacity to fulfill the orders), demand goes up and causes stock-out at supplier resulting in long lead-times to restock.
Integrated Network Manager APAC	• Planning System Errors & Manual Overrides. Intermittent system errors (e.g. safety stock updates, long supplier lead times) trigger wrong PO quantities. Teams must detect anomalies and execute manual corrections until fixes land • Plan orders vs priority orders: rare but large same-day priority drops (200-300 lines) create short-term capacity strain despite generally "soft" demand • Immature automated stock allocation. Contracts/TPMS order exist but automated stock allocation is immature, manual, and not scalable across sites
Supply Network Specialist	• Data fragmentation where data is spread across excel sheets making it difficult to analyze. • Supplier constraints: long lead times and high MOQ negotiated for lower prices often lead to high capital binding and inflexibility. • Limited visibility, lack of real-time visibility into how supplier decisions affect downstream operations and customer satisfaction. • Manual processes, many double checks and validations are manual, including verifying purchase orders and matching forecasts.
Customer Service Excellence Manager	• Lead time & availability issues • Order follow-up & tracking • Obsolete parts confusion • Tool fragmentation • Manual workload • Limited e-business adoption
Distribution Center Manager Brazil	• Lack of pre-shipment and in-DC visibility since they have no WMS. • Reactive communication with customers. There are no proactive alerts. • Prioritization gaps (no downstream impact when reallocating parts) • Manual processes and fragmented tools • Lack of impact alerts when forcing deliveries that affect other orders
Supply Optimization Manager	• High dependency on OEM suppliers • Manual risk detection • Escalation inefficiency (penalties rarely used) • System fragmentation (supplier collaboration tools hard to implement) • Limited dual sourcing
Director of Planning & Quality	• Reactive processes • Ownership ambiguity • Limited scenario planning • Sustainability blind spots

Sales Administration Manager	• Fragmented systems • Lack of End-to-End visibility and unified tracking • Connected functions (and Sales Administration) working in siloes • Data Quality and Master Data issues • Long learning curve for new employees, reactive communication with customers • Limited customer-centric insights
Sales Administration Manager	• Lack of End-to-End visibility for SAC teams and customers • Customs delays due to fast-changing rules • High workload from repetitive status queries • Resistance to standardization in some markets
Logistics Solutions Managers (2 Interviewees)	• CC implementation may require organizational shift. To make use of the End-to-End visibility, a new End-to-End team might be necessary • System limitations in TMS, cannot track beyond shipment to customers • Cannot determine if parts in a shipment are critical or already late • Fragmented and unstructured data • Integration complexity • Customer Service limitations – there's a need for better tools to notify customers of delays and provide shipment status

4.3.1 Visibility

Lack of visibility, particularly real-time and end-to-end visibility, emerged as one of the main challenges across all functions within the current spare parts network. Employees often highlighted the difficulty of obtaining a clear overview of order status, inventory positions, and the progress of transport. Current processes require navigating through multiple SAP transactions and fragmented reports, which not only slows internal workflows but also creates a steep learning curve for new hires within some functions, especially within Sales Administration Centers. Interviewee R mentioned that the learning curve for new hires could be up to 1 year. These limitations hinder proactively communicating with customers, and forces teams into reactive problem-solving when disruptions occur. From a customer's perspective, expectations for real-time tracking and transparency are growing rapidly, that the spare parts network currently do not deliver. These shortcomings undermine operational efficiency, delay escalations, and diminish customer trust, making improved visibility a prerequisite for enabling proactive decision-making and enhancing overall network performance. Table 8 presents the sub-themes (Sub-codes) identified in the case study, indicating who mentioned them and the corresponding quotes.

Table 8: Sub-themes related to visibility discussed by interviewees and corresponding quotes

Sub-themes (sub-codes)	Interviewee(s)	Quotes
Fragmented Systems	Optimization Director (J), Integrated Network Manager Americas (D), SR Business System Analyst (E)	"There is fragmentation where multiple systems (ECC, EWM, etc.) operate independently with no clear ownership of handovers" (J) "Disconnected systems (SAP, TMS) hinder the end-to-end visibility" (D) "There are multiple channels (e-commerce, fax, phone, etc.) which causes inconsistent visibility" (E)
Lack of End-to-End Tracking	Sales Administration Manager (R), DC Manager Brazil (O), Sales Administration Manager (S), Planning & Quality Director (Q),	"I don't have a full view and need to look one by one", "Today we only see manually, line per line. Would be good with an overview from Command Centre" (R) "Sometimes we have good traceability in load, good traceability in customs clearance, [but] not so good traceability inside my operations… I have a grey zone" (O) "Lack of visibility both for SAC teams as well as for customers" (S) "End-to-end tracking is missing" (Q)
Transparency Gaps	DC Manager Brazil (O), SR Business System Analyst (E)	"Information is not available in an easy way to the customer" (O) "Lack of end-to-end transparency for orders, shipment, and supplier performance" (E) "Customers have inability to track orders independently which leads to a high support load" (E)
Customer Self-Service gaps	Customer Excellence Manager (N), Sales Administration Manager (R)	"Customers expect real-time updates and self-service capabilities (N)" "The most common query and question is 'Where is my order'" (R)
Proactive Communication	Customer Excellence Manager (N)	"Customers expect proactive, accurate updates on order status and delays" (N)

The sub-themes collectively illustrate that visibility challenges in the spare parts network are common across the network and in the different functions. Fragmented systems and lack of end-to-end tracking create blind spots that can force employees to rely on manual checks and informal communication channels. This increases the risk of errors and delays. Reactive communication further magnifies the issue, as updates are frequently triggered only after customer complaints. The absence of both customer-facing and internal self-service capabilities adds to the workload of SAC teams and slows decision-making. Data integration gaps together with unclear ownership were mentioned too. These points were consistently raised, emphasizing the impact that limited visibility has on daily work and coordination.

4.3.2 Delays

Delays are another emerging and recurring challenge identified across multiple interviews. The delays are primarily linked to, for example supplier performance, system limitations, customs, and fragmented visibility. The current processes typically rely on static confirmation updates and manual checks, making the detection for delays reactive. This approach limits proactive risk management and often results in late escalations, which in turn can have negative impact on the end-customer. While some delays and supplier lateness do not always hit customers due to stock buffers (e.g. Supplier Delivery Performance is 89%, yet availability is still 95%), long delays, non-stocked or critical components can (Interviewee K). These issues can significantly disrupt maintenance events. The existing systems do not assist particularly well as they treat all delays similarly, without distinguishing between those with high customer impact and those with minimal consequences.

From a customer perspective, the expectations for proactive communication and visibility over their ordered parts and potential delays are growing. The Customer Excellence Manager (Interviewee N) noted that 9% of all customer complaints relate to order follow-up and delay notification. This highlights the importance of timely and transparent updates. Additionally, Interviewee N along with the Logistics Solution Managers (T), empathized that delays are often worsened by the need to ship complete orders rather than partial shipments. As discussed with Interviewees T, even if most order lines are ready, a single delayed component can block the entire order. This suggests opportunities for dynamic planning, such as ordering historically problematic parts in advance, or splitting shipments when appropriate. It was further discussed that in some cases, a single component within an order can become stuck in customs, in turn delaying the entire shipment even when all other parts are cleared and ready to be released. The main sub-themes are presented in Table 9.

Table 9: Sub-themes related to delays discussed by interviewees and corresponding quotes

Sub-themes	Interviewee	Quotes
Reactive Delay Detection	Sales Administration manager (R)	"We only consider it a delay if we're… delivering after the first confirmed… as soon at the latest confirmation is postponed… that'll trigger a new delay" (R)
Supplier Performance Gaps	DC Manager Brazil (O)	"Availability shortfalls are driven mainly by supplier delays and system issues" (O)
Fragmented systems	Manager Inventory & Planning (H)	"Current tools lack proactive alerts, no system-level notification for trends like increasing transport times or supplier delays" (H)
Documentation & Customs	Sales Administration Manager (S), Integrated Network Manager Americas (D)	There are fast-changing and specific documentation requirements where rules can "change from one day to the next, causing rework and delays" (S) "Disconnected systems with lacking product classification and origin data affect customs clearance times, increasing delays" (D)
Customer Expectations	Customer Excellence Manager (N)	"Customers expect proactive, accurate updates on order status and delays" (N)

The sub-themes collectively show that delays are often detected late and handled reactively. Interviewees highlighted that delays often can stem from supplier performance issues, fragmented systems, and customs-related complications. Furthermore, it was noted that customer expectations are increasing. Lastly, the Global Operational Support & OT Security Manager (Interviewee G) expressed that there is a "Zero-sum workload reality", where the team usually balances competing urgencies. This means that by helping one request faster will often result in delays for another, underscoring the complexity of prioritization in a spare parts network. In addition, inconsistent or incomplete master data, such as HS-codes or country-of-origin details, was identified as a root cause of compliance issues and customs delays, further amplifying the challenges.

4.3.3 Prioritization

Prioritization was identified as a critical challenge within the spare parts network. In situations where the resources are limited, supplier delays occur, or sudden demand fluctuations which in turn create competing emergencies. Unlike visibility or delay issues, which primarily affect the information flow and planning accuracy, prioritization directly influences operational execution. Several interviews revealed that the current practices are largely manual and reactive, relying on local judgement instead of standardized logic. For example, First-In-First-Out (FIFO) principles are often applied for handling orders, which creates inconsistencies across regions and limits the ability to make decisions based on global customer impact. Without a structured approach, relying on convenient options or FIFO prevents differentiation between orders based on strategic importance or customer impact, often covering critical needs behind favorable averages. Table 10 presents the main sub-themes identified, along with representative quotes from interviewees.

Table 10: Sub-themes related to prioritization discussed by interviewees and corresponding quotes

Sub-themes	Interviewee	Quotation
Manual Prioritization	Director of Optimization (J)	"There is no structured process for prioritizing or resolving disruptions." (J) "There can for example be a mismatch between pick workload and staffing which causes unpicked backlogs… need prioritization and rapid staffing actions." (J)
Lack of Criticality Logic	Sales Administration Manager (R), Director of Optimization (J)	"We don't have criticality calculated today to sales order… average doesn't mean anything" (R) "Current practice is largely FIFO with no end-to-end criticality logic, masking customer-level pain behind favorable averages." (J)
Local vs Global Prioritization	Director of Optimization (J)	"Site-level choices optimize for convenience (what is easiest to pick) versus global customer impact, leading to inequitable country outcomes" (J) "Define a unified KPI framework (e.g., perfect order) and consistent thresholds to steer all teams toward the same outcome." (J)
Customer Segmentation	Manager Planning & Inventory Optimization (H), Replenishment Manager (K)	"Needs explicit prioritization (e.g., contract customers first) and clearer rules when shortages occur" (H) "Contracts should carry higher priority… for this special order we want that every single line is delivered 100%" (K)
Impact Insights	DC Manager Brazil (O), Replenishment Manager (K)	"[There is] no [insights of] downstream impact when reallocating parts" (O) "FIFO and breakdown priority is acceptable, but staff need impact alerts when forcing deliveries that affect other orders." (O) "At any time, we have about 25 to 30 thousand order lines… the crucial point for us is to have the right prioritization." (K)

The complexity of prioritization is heightened by the lack of structured processes and supporting logic. This gap often leads to organizational friction, as markets (SAC teams) frequently escalate requests as "urgent", creating ticket overload and subjective decision-making. The Replenishment Manager (Interviewee K) warned that if escalation mechanisms in the future Command Centre are too non-restrictive, "volume could explode and erode prioritization". This underscores the need for clear thresholds to prevent alert fatigue and focus on the truly critical cases. With 25-30 thousand open order lines, the core need is to decide which lines to act on based on impact. This could become difficult if every issue as mattered as “urgent”. The Replenishment Manager further stated that “Contracts should carry higher priority targets (even towards 100% availability)”, which in turn will influence routing, escalation, and allocation of inventory. “Pegging” is a term brought up in interview with the Global Planning & Data Experts (Interview I) and refers to the detailed allocation of inventory to specific orders, allowing dynamic decision on who gets limited stock based on impact and global priorities. This is a capability related to prioritization that could benefit the transition from a reactive process into a proactive and data-driven one, which becomes even more critical when considering the challenges associated with lead-times.

4.3.4 Lead-times

Another common challenge brought up during the interviews that impacts the spare parts network is the long lead-times. Lead-times are especially important to address since it directly affects the customer. The Customer Excellence Manager mentioned that the number one complaint from customers, when returning feedback on their orders, is the long lead-times, which often undermine service reliability and satisfaction. This issue often ripples across several functionalities and creates tension between what is previously said regarding, for example delivery date, and what operations can realistically deliver.

Interviews revealed that lead-time visibility is fragmented, with limited integration between upstream suppliers and downstream distribution centers. Promised lead-times are often misaligned with actual performance, in turn creating unrealistic promises to customers which lead to complaints and have negative effects on KPIs. Escalation mechanisms frequently compensate for poor predictability rather than addressing root causes, leading to inefficiencies and additional costs. Interviews further showed that structural factors, e.g. low-volume parts and specialized components, make the spare parts more subjected to long lead-times. Having these on stock, however, would result in increased inventory costs and not be worth it in the long run. The network is therefore relied on make-to-order strategies. While this is usually efficient and cost-effective, the approach can lead to significant delays during urgent maintenance events. The Customer Excellence Manager highlighted the operational impact of these delays and said that “Unfulfilled order lines vs complete orders is a big difference for some [customers]. One missing line means no maintenance event”. This illustrates how even a single delayed component can halt crucial maintenance events. If a customer needs to address the event for their machines to be running, and the spare parts network has long lead-times either due to suppliers or intra-logistics, this leads to severe consequences for the customers and will reflect on customer satisfaction. The main sub-themes are presented in Table 11.

Table 11: Sub-themes related to lead times discussed by interviewees and corresponding quotes

Sub-themes	Interviewee	Quotes
Long supplier lead-times	Integrated Network Manager APAC (L), Supply Network Specialist (F), Supply Network specialist (M)	"Long supplier lead times challenges the service" (L), "One day the lead times go from 12 days to 200 and then to 600" (F), "Long lead times combined with high MOQ make planning very challenging and often lead to high capital binding and inflexibility" (M)
Impact on Maintenance Events	Customer Excellence Manager (N),	"Lead time can be so many weeks (…) for maintenance, you know it's not so important for the availability, but we measure here usually on order line (…) if one line is missing; they cannot do the maintenance event" (N)

To overcome these challenges, several interviewees spoke of the potential of the Command Centre (CC) initiative with high hopes as a transformative capability. However, to address the lead-time challenges will according to some interviewees probably require more than gradual steps and fixes, it will need a systematic shift toward predictive and integrated planning. The ambition is that this can be provided by the CC, combined with DT capabilities. By gathering data sources and creating a virtual presentation of the spare parts network, DTs can simulate lead-time scenarios, test alternative strategies and reorganization of logistical flows (Moshood et al., 2021). Using DTs has the potential to move from static averages to predictive models and scenario-based planning. This would allow organizations to anticipate disruptions better and align with reality. These capabilities not only address the root causes of lead-time variability but also build the foundation for decision-support.

4.4 Desired Capabilities of the Command Centre

The envisioned Command Centre (CC) is not just a dashboard, but a living, integrated nervous system for the Supply Chain. With the CC being a board solution and connecting several data sources and functionalities, employees from different functions have desire capabilities they would like to see in the new system. These capabilities are presented in Table 12. In the sub-sections that follow, some selected capabilities that were mentioned often and through the interviews will be mentioned and further explored.

Table 12: Desired capabilities, descriptions, expected benefits and mentioning by interviewees

Capability	Description	Expected Benefit	Mentioned By Interviewee(s)
Risk sensing & early warning engine	Detect disruptions, demand/lead-time spikes with thresholding to avoid noise; external risk signals (weather, geopolitics, capacity); real-time risk scoring with recommended actions.	Earlier intervention, fewer stockouts/expedites, better service levels.	B, H, I, J, K, P, Q
End-to-end & Real-time Visibility with accurate ETA (incl. customs)	Unify carrier, supplier, DC and customs data into a single flow view; pragmatic near real-time refresh; role-based presets for fast lookups. Connect Sales Orders, Shipment, and Purchase Orders. Link orders, shipments, escalations, contracts and notes across the lifecycle.	Faster responses, fewer delays and 'where is it?' contacts; higher customer satisfaction. End-to-end traceability and faster investigation/resolution.	B, I, J, K, L, N, Q, R, S, T
Action orchestration, workboards & role-based ticketing	Central brain to detect, prioritize, direct; operational workboards; role/RACI ticketing; reminders; playbooks and incident knowledge base; unified communication across regions.	Faster resolution, consistent execution, reduced person-dependency.	B, G, J, I, J, N
Simple, role-adapted dashboards	Provide personalized and customizable dashboards tailored to specific roles, showing the most relevant information for decision-making.	Clear view of operations to allow faster and more confident decisions	L, M, N, R, S, T
Decision support, simulations & trade-offs	Decision previews with pros/cons; LT vs Cost vs CO_2 recommendations; dynamic parameter sandbox for supplier LT/MOQ; total-cost views (EOQ/MOQ); guardrails with simple overrides.	Smarter negotiations and allocations; balanced sustainability, cost and service.	B, H, L, M, P, Q
Allocation & impact aware prioritization	Pegging visualization and explainable allocation rules; criticality and contract-weighted scoring; customer-impact prioritization; comparative impact logic and consequence previews.	Fair, explainable allocations in shortage; revenue and service protection.	B, F, I, K, O, T
Customer self-service tracking & proactive notifications	Customer/SAC-facing portals with global risk pushes and proactive delay/customs alerts; unified voice in supplier/customer communications.	Deflects 80–90% inquiries; improves transparency and reduces manual workload.	J, K, N, R, S
Integration & SDAR data fabric with governance	Supplier + transport integration (incl. local providers); Salesforce, ECC and portal integrations with sensitive data redaction; SDAR aligned data fabric; secure-by-design rollout.	Single source of truth; fewer manual loops; reliability and adoption.	B, D, G, M, N, O

Performance & KPI framework + data quality	KPI cockpit (Availability, Inventory Turns, Lead Time, Cost Savings, Delivery Precision); unified KPIs; criticality weighted KPIs; reliability SLs; data health tiles (feed freshness & blind spots).	Aligned priorities, measurable impact and trusted data; avoids "DT gone wrong".	E, H, J, L, P, Q, T
Automation & AI agents	Self-optimizing flows; AI agents to parse orders/emails, detect data gaps, auto fix packages, and dispatch tasks with Service Level Agreements (SLAs); progressive ML assisted automation.	Lower manual workload, higher throughput, fewer errors.	C, H, J, S
Security, compliance & guardrails	Secure by design rollouts; credit limit shipment gate; sourcing guardrails (MOQ rules) with simple overrides; supplier redaction in customer views.	Lower operational and compliance risk; fewer failed shipments; safe transparency.	G, J, P, Q
Data freshness, sync health & exception engine	Near real-time (e.g., hourly) refresh with synchronization monitors except engine to surface only meaningful alerts.	Reduced noise and quicker reactions; higher user confidence.	B, K, L, Q
Deviation detection & trend analysis	Detect large deviations in demand/stock and repeated issue patterns; surface trends and recommended follow-ups (e.g., RCA).	Earlier interventions, fewer repeat incidents, and targeted improvements.	H, K, L, T
Flow optimization & capacity balancing	Bottleneck detection with dynamic resequencing; Time-to-Stock tracking/reduction; capacity vs staffing balancing using predictive signals.	Shorter lead times, better availability, smoother ops.	C, J
Supplier escalation tracking & expedite lanes	Track supplier escalations with clear expedite options, lanes and costs; propose alternative sources when late priority orders are detected.	Faster recovery from delays at optimal cost; clearer decision paths for escalations.	B, H, K, O, Q
Warehouse congestion prediction & workload re-routing	Predict upcoming congestion and dynamically re-route work or notify resource managers to balance capacity across shifts and zones.	Smoother operations and reduced delays in outbound/inbound flows.	B, C, I, J

4.4.1 Real-time Visibility & Dashboards

Real-time visibility was consistently mentioned as the most critical capability for the envisioned Command Centre (CC). Interviewees highlighted that the current state of visibility is fragmented across multiple systems and reports, requiring significant manual effort and forcing employees to navigate through multiple Power BI reports and SAP transactions to answer basic status queries. This fragmentation and reactive approach not only slow internal workflows but also limit the ability to provide timely and accurate updates to customers, resulting in increased workload for several functions.

The envisioned CC will connect transport, planning, operations, and warehouse systems. As the Planning & Quality Director emphasized, visibility should not only unify underlying systems, but also define where things go wrong, ensuring that even minor disruptions are flagged early and paired with actionable recommendations. This capability should extend beyond internal transparency to include customer-facing visibility, enabling proactive communication and self-service tracking. Distribution Center managers point out that today's communication is too reactive. Customers increasingly expect real-time updates and accurate estimated times of arrivals (ETAs), a demand currently unmet due to siloed systems and inconsistent data synchronization. The Customer Excellence Manager highlights the customer view: people want to "*understand every minute*" where their shipments are. He emphasizes the challenge of keeping data synchronized in near-real time and the importance of tailoring dashboard views to balance too much versus too little information. One of the interviewed Sales Administration Managers (interviewee S) echoes this. The biggest customer benefits is a single accurate view of "*where the order is in the flow*" including customs. Specificality matters, but supplier identities should remain redacted. Sub-codes to the capabilities (codes) mentioned in Table 12 related to visibility are presented in Table 13.

Table 13: Capabilities along with their corresponding description

Capability	Description
End-to-end flow integration	Linking purchase orders, sales orders, shipments, and customs data into one consolidated view for complete traceability of the entire order lifecycle.
Customer transparency	Self-service portals for real-time tracking and proactive notifications. This feature would be beneficial to meet growing expectations for real-time ETAs and shipment tracking.
Decision support layer	Surface contextual insights and recommend actions when deviations occur, including simulations of trade-offs.
System integration	Seamless connectivity between SalesForce, ECC, WMS, and the CC is essential to ensure a single source of truth, with sensitive supplier data redacted in customer-facing views, showing timing and location without exposing sourcing details.

Interviewees envision a platform or dashboard where teams can give customers a single, accurate view of where the order is in the flow and confidently call customers and say: "*We have taken these actions, the order will still arrive late, but the impact is minimized*". Furthermore, customers should too be able to track their order at any moment in the same dashboard but tailored to a customer-facing view. This capability is foundational for improving customer experience, reducing manual workload, and enabling proactive, data-driven decision making across the spare parts network.

Ultimately, real-time visibility is not just viewed as a tracking feature, it is about connecting the customer side with the supplier side while lowering manual interaction, as the replenishment manager noted. Where simple dashboards will ease operational workloads.

4.4.2 Detections of Deviation & Actions

A recurring theme across the interviews was the need for a system that not only monitors the network but actively detects deviations and proposes corrective actions. As described by the Director of Planning & Quality (interviewee Q), the future lies in “a system that somehow connects all our underlying systems: transport, planning, operations, EWM.” She imagines an environment where everything flows silently when it should, but where “if even the smallest thing goes wrong… it should rise immediately.” This rewires more than alerts: it requires actionable decision support and simulation. The system should not only flag disruptions but propose system generated options, simulate trade-offs (stock against risk, time against CO_2 against cost), and guide users toward the best choice.

Users in the spare parts network often must navigate many separate Power BI reports and filters in today’s work processes. However, the vision for the future with the Command Centre will provide a platform where insights are served in one place. The Planning & Quality Director emphasized that customer service staff should be able to track orders in real-time and call a customer with confidence: “*We have taken these actions; the order still arrives late, but the impact is minimized*.” Equally, customers should always have self-service visibility into where their order is at any moment. Survey responses reinforce this as one of the Supply Network Specialists (Interviewee F) and Digitalization Manager (Interviewee B) highlighted the need for and importance of connecting purchase orders (PO) with sales orders (SO) and identifying issues early.

Today, deviation detection is largely reactive, relying on manual checks, fragmented reports and customers calling in raising the problem. Interviewees emphasized the importance of early warning mechanisms capable of sensing disruptions before the escalate. The replenishment manager (interviewee K) highlighted the need for threshold-based alerting to avoid “*alert fatigue*”, noting that “*not all delays matter… do we need a notification every time a purchase order line gets delayed by three days? No*.” This underscores the necessity of distinguishing between noise and meaningful signals, ensuring that alerts focus on deviations with real operational or customer impact. The manager stresses the need for a single voice to the supplier, with traceability and purchasing specialists copied in, to ensure both speed and accountability.

Detection alone is insufficient without actionable insights. As the Planning & Inventory Optimization Manager noted, the system should be a hub that provides multi-horizon alerts, distinguishing between early risks and immediate issues, and pair with decisions previews. One Supply Network Specialist (interviewee M) echoes this and emphasized the need for interactive tools to “*play dynamically with parameters*” and use chat-based queries alongside dashboards. Supplier portals could reduce email loops, but sensitive data (like prices) must remain hidden. Another Network Specialist (interviewee F) highlighted the importance of systems that integrate data together, surfaces problems early, and proposed next actions. When a supplier slips, users want immediate suggestions for alternatives (these could be based on past buys or product/producer families) and impact projections. Examples of issues that can be detected and suggestions for what action can be taken can be seen in Table 14.

Table 14: Detect and actions submitted from employees in the survey

Detect	Action
High-priority customer issue	Escalate to relevant team and flag in dashboard with resolution timer
Planned order at risk of delay	Notify planning team and suggest alternative dispatch options.
Inventory below safety stock	Trigger replenishment proposal or alert responsible planner
Forecast deviation vs. actual demand	Recommend forecast adjustment and review with demand planning.
Repeated issues with specific customers or product	Flag for root cause analysis and improvement initiative.
Late priority order	Ability to notify resource manager or reroute work
PO causing late SOs	System to propose new expedited delivery dates
Forecasted warehouse congestions	Notify relevant team
Bottleneck in Warehouse early warning	Ability to notify resource manager or reroute work

The Optimization Director expressed a need for a central function that should continuously monitor flows, detect deviations, and direct operations with authority across silos. He envisioned capabilities such as AI agents to scan for data gaps (e.g., missing master data) during customs processes, predictive signals to detect capacity issues between pick workload and staffing, and staffing recommendations to prevent backlogs. An additional ambition is to include exogenous risks into daily operations through structured geopolitical briefings and alerts from transport partners and news sources, translating signals into actionable decisions.

4.4.3 Network Wide Prioritization Method

A robust prioritization and pegging logic are essential for managing constrained resources in a global spare parts network. Pegging refers to the process of linking demand transactions to supply transactions, this allows companies to trace which supply is intended to satisfy a certain demand. This process is critical for maintaining traceability and transparency within the supply chain. This combined with prioritization logic enables The Company to answer critical questions like *"Who gets what, when and how?"*. This capability ensures fairness in allocation decisions, particularly during shortage situations, and forms the foundation for the Command Centre (CC) visualization.

Insights from interviews underscore that prioritization must move beyond simple FIFO principles toward a structured, impact-based approach. Orders tied to contractual obligations or critical maintenance events should receive the highest priority, while backlog orders with sufficient buffer stock can be deprioritized. As the Optimization Director emphasized, prioritization logic should be anchored in customer impact, ensuring that items or order with direct customer deadlines are prioritized over those with lower urgency. Furthermore, he advocates systematic incident logging, building playbooks for recurring issues, and using generative search to accelerate problem-solving.

Beyond inventory allocation prioritization extends to transport decisions. As the Director for Planning and Quality noted, mitigating transport delays often involves trade-offs between time, cost, and environmental impact. For instance, one option may offer shorter lead times at higher cost and CO_2 emissions, while another provides lower emissions at the expense of longer transit times. The CC should therefore incorporate decision-support tools that simulate these trade-offs, enabling users to balance expedite costs against sustainability objectives. This aligns with The Company's long-term ambition of moving towards full emissions measurements across all movements.

Complementary perspectives reinforce this vision. For example, the Manager of Planning & Inventory Optimization mentioned the importance of "*highlight[ing] potential issues if current trends continue (e.g., forecasted delays, inventory shortages)*." And to display improvement metric over time "*showing how much we've improved in key areas (e.g., lead time, service level, issue resolution speed)*". He suggests starting with assistive proposals and gradually letting the system automate repetitive decisions as trust builds. He also imagines gamification features to motivate teams by showing the savings, days gained, or deliveries improved by their actions. One Supply Network Specialist (Interviewee M) reinforced this in the survey, requesting "*simulation of changes in stocking parameters and their impact on stock*", highlighting the importance of scenario-based decision support.

5. ANALYSIS

In this chapter, the empirical data is synthesized with the theoretical framework to address the research questions. It evaluates the identified network challenges through e.g. the lens of supply chain visibility to determine how Digital Twin technology can foster collaboration and break down silos. Thereafter, the SDAR framework is applied to translate the employee needs into practical monitoring and response systems. The chapter also presents the value-to-effort matrix to prioritize technological capabilities based on their expected value and required implementation and overall effort. Finally, the organizational barriers and the gap between current reality and the long-term vision are discussed.

5.1 Introduction of DT Framework

Before analyzing the challenges of the spare parts network and how DT capabilities can be utilized to bring value, it is instrumental to understand the relationship between data sources, potential users, the foundation behind the planning system and Command Centre (CC), and customers. This chapter introduces that framework for how DT should enable the CC to have an intelligent nerve center with several capabilities. Figure 17 presents the framework scheme and consists of three core components: The Data Foundation, The Digital Twin Architecture, and User Interface & Dashboards. This figure is produced based on analysis from literature and interviews with relevant interviewees such as Optimization Director and Digitalization Manager. The figure has been validated by the Digitalization manager.

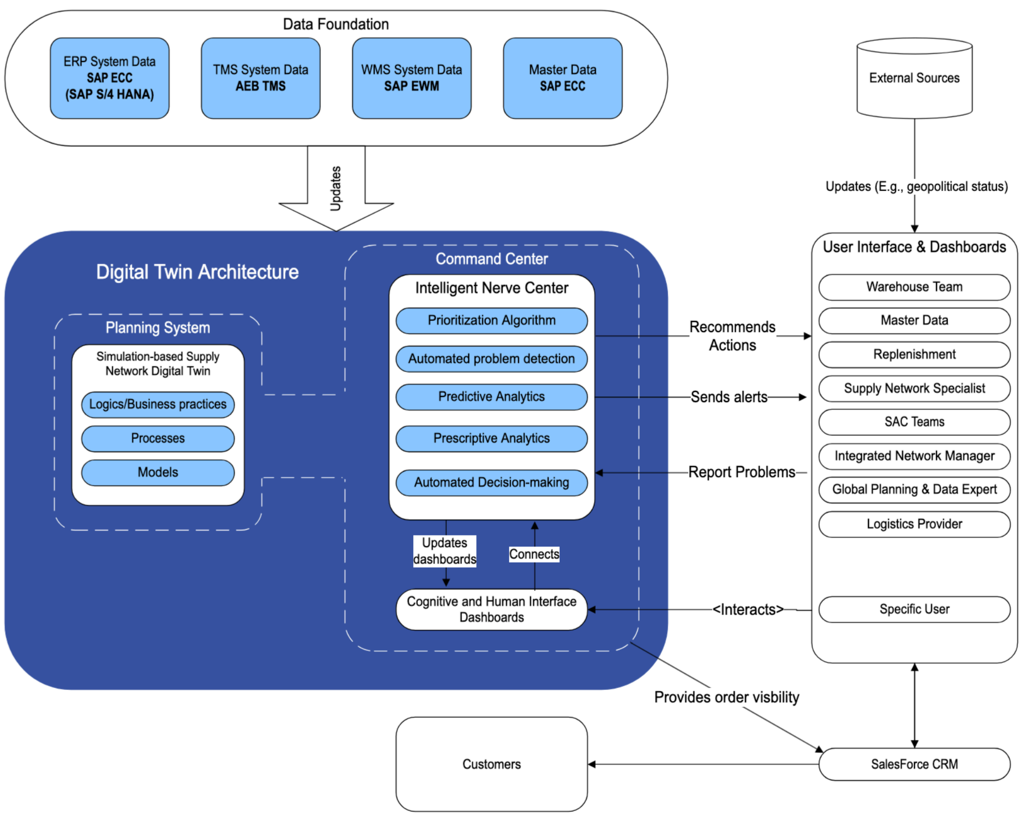

Figure 17: Framework for Digital Twin implementation at the spare parts network

The Data Foundation relies on multiple internal data sources, these are the ERP System Data, the TMS System Data and the WMS System Data. The ERP System provides data with an overview of order flows, master data and transactional records. The TMS System includes logistics data, transport status, fault codes, and carrier performance. The WMS System provides warehouse data. Master data includes static attributes for company entities, which are critical for compliance and accurate process execution. It is crucial to collect these onto a single platform where they then can be connected. That is The Company's current situation how much they have accomplished. First, after that it is possible to connect purchase orders, sales orders, and shipments, and gain an End-to-End view along with a single truth. The data foundation will together combine all the relevant data and feed it into the DT Architecture.

DT Architecture is the main component of the framework and will be the technology enabling advanced capabilities. The capabilities can be divided up into two sections the "Command Centre" and the "Planning System", both systems are based on the same data.
The planning system is expected to provide great benefits to the spare parts network and a crucial step for The Company to stay competitive. Some capabilities are expected to be included in it while others expressed in the interviews are more relevant for the planning system rather than in the CC. Some capabilities are shared, and others are exclusive to CC since they are irrelevant to the planning team. As the focus for this thesis is the CC and how DT technology can benefit it, the benefits for the planning system will not be analyzed as in depth. However, the planning system will utilize several capabilities which are often linked to DT technology, such as simulation to enable forecasting, along with prioritization logic and detection of deviations.

5.2 Command Centre Value Drivers

As one of the main pillars of The Company is to provide superior customer satisfaction, the main goals for the Command Centre (CC) are therefore the same. The CC value drivers focus on improving Customer Satisfaction through the two critical areas that were the main critique from customers: Real-Time Visibility and Delays to Customers. Customer satisfaction is built on KPIs Sales Order Backlog, Service Level, and Customer Excellence. To increase customer satisfaction, the KPIs need to be improved. The relation can be seen in Figure 18. First of is visibility where all the information from the different information sources needs to be connected to provide real-time end-to-end visibility. Delays are more complicated since they depend on a lot more factors, but the risk of delays is mitigated by the CC and the process of this will be explained in the latter part of this analysis. In Figure 18 you can see the specific issues that the CC is expected to address, their general area and then they all impact Customer Satisfaction. It is by improving customer experience that value is gained from the CC.

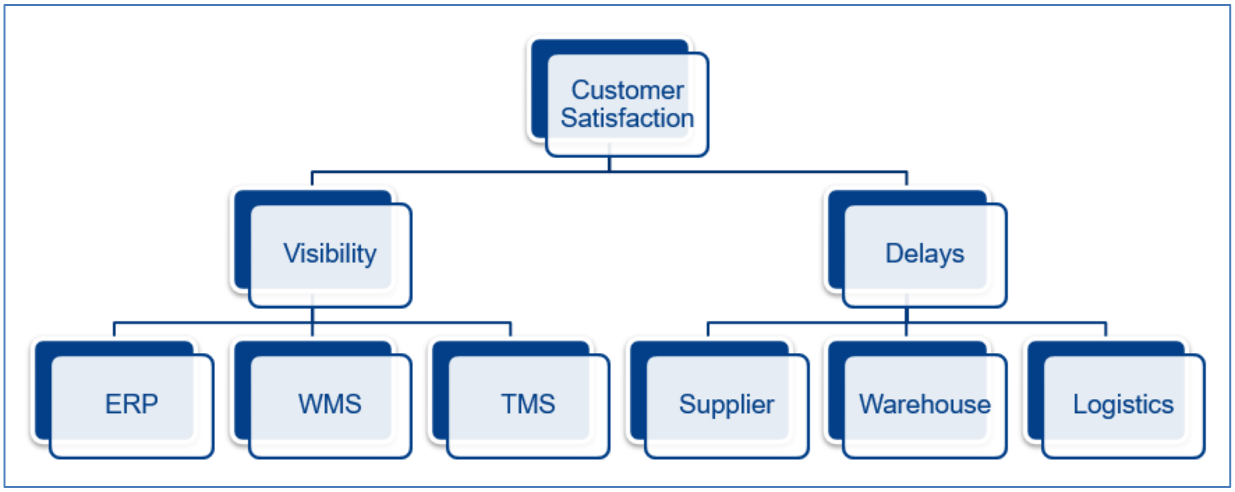

Figure 18: Key factors affecting customer satisfaction

To gain total value from the CC, value must be gained further down the tree as well. The issues of real-time visibility and delays to customers differ greatly. Real-time visibility will provide value by allowing customers to know where their products are located and when they will arrive, allowing for more precise planning and lowering the probability of a longer disruption. Overall delays to customers can be caused by several factors and all actions to mitigate any delays would be appreciated by the customer and in turn improve the customer's experience. The sub-categories for visibility and delays are trickled down to the data sources, and where delays can occur respectively. What causes the delays in the first place will be further analyzed.

5.3 Visibility

The lack of real-time and end-to-end visibility is a reoccurring issue the empirical findings confirm that visibility in the spare parts network is currently fragmented and one of the two main pain points. The interviews and survey responses consistently highlighted visibility as a key capability that the Command Centre must deliver. Visibility for employees but also for customers. The lack of End-to-End transparency and absence of customer-facing tracking tools suggest that the organization is operating at a lower maturity level in terms of the visibility pillars defined in section 3.2.1 by Wei & Wang (2010).

The value of having high visibility is different for each actor in the network. For customers, it is defined as faster and more proactive communication, accurate ETAs, and improved trust. Operationally, it would reduce ad-hoc crisis management and the amount of manual status checks. This could in turn allow resources to be allocated to higher-value tasks instead of time-consuming information retrieval. It would also mean an accelerated decision-making process or increased decision support to minimize errors. Increased decision-making could include trade-offs generated by simulations. Strategically however, this would mean a more robust network resilience, alignment with sustainable goals, increased productivity, KPI alignment across the board, and activities that drive customer centricity. Literature reinforces that Digital Twins (DTs) have the capability to provide relevant benefits by transforming visibility from a static snapshot into real-time representations of the network. To assess the visibility within the spare parts network, the four pillars outlined in section 3.2.1 are applied. They are visibility for sensing, learning, coordinating, and integrating. These are grounded in literature and serve as analytical lenses through which the spare parts network can be examined. Together these pillars provide a conceptual foundation for analyzing and evaluating the spare parts networks' current state of visibility and identify gaps that DT capabilities can address. The empirical findings and identified gaps related to each pillar are presented in Table 15.

Table 15: Identified gaps in the empirical findings related to each visibility pillar

Pillar	Current state and identified gap
Sensing	Reactive detection, fragmented data connections cause delayed risk identification, Customs "grey zone"
Learning	Limited post-incident analysis
Coordinating	No clear ownership of processes, lacking handoff and pegging logic, resulting in siloed roles and unclear resource allocation
Integrating	KPI misalignment, no customer-facing views create fragmented performance alignment

The gaps identified across the four pillars in the empirical findings can be addressed through DT capabilities found in the literature. For sensing, DTs can consolidate data streams into a unified layer and enable real-time monitoring, drifts in ETA, and customs bottlenecks. This can in turn improve responsiveness and resilience by alerting the organizations to changes as they occur (Moshood et al., 2021). Furthermore, DTs can support predictive simulation of disruption impacts on performance (Ivanov, D. and Dolgui, A. 2019). This would enable a more proactive risk management approach. For learning, DTs can help uncover inefficiencies and support continuous improvement by capturing data and enabling feedback loops (Iranshahi et al., 2025). For coordinating, DTs provide operational dashboards and simulation tools that can enable scenario planning and resource optimization (Iranshahi et al., 2025). Finally, for integrating, DTs can with the help of agentic AI to create a unified digital environment (Ivanov, D. and Gusikhin, O. (2025) where actions taken are linked to performance metrics, creating transparency and a single source of truth.

In practice, improved visibility will rely on connecting the data sources and leveraging DT foundations. Once after the data streams are in place, dashboards and monitoring tools can enable real-time visibility.

5.3.1 Data and Digital Twin Architecture

One of the core functionalities of the Digital Twin (DT) is to deliver end-to-end real-time visibility across the supply chain. This information already exists in various systems; there is currently no unified view of the entire chain. The DT will receive information from all necessary data sources and display it in an integrated dashboard. However, there is significant effort to achieve this. Data integration is critical as visibility depends on connecting streams from ERP, TMS, and WMS into a unified layer. The importance and prioritization of these systems according to the interviewees were interpreted as ERP, WMS, and TMS. This is confirmed from the survey and can be seen in Figure 19, which displays the relevance of different data sources. External data sources will be postponed to future stages of the Command Centre (CC) development. This decision was based on a qulaitative weighting of perceived value and implementation effort. Perceived value was data retrieved from the employee survey, indicating that external data is lowest priority for the workforce as they prioritize stabilizing internal visibility first. The effort aspect was derived from the Digitalization Manager and Digital Twin Engineer. The Digitalization Manager highlighted the development costs and technical complexity required to normalize unstructured external data into existing data infrastructure. However, prioritization is not straightforward. Most interviewees use SAP ECC daily and will therefore consider ERP data as most important, while for customers according to the Customer Excellence Manager, TMS data is of higher importance. Consequently, Figure 18 reflects employee perspectives only and does not represent the full picture.

Figure 19: Data sources (where the employees prioritize the data to come from) ranked

ERP Visibility lets the system access data from Enterprise Resource Planning, which is a system that provides a comprehensive overview of the entire supply chain, enabling traceability from the creation of a sales order to the completion of a purchase order. TMS Visibility gives access to the Transport management system which enhances visibility across logistics operations, including transportation from suppliers to distribution centers, inter-warehouse transfers, and deliveries to customers. This information is usually provided from carriers to the TMS. Finally, WMS Visibility allows visibility into the warehouse management system. This encompasses inbound and outbound processes, picking operations and inventory management. Real-time insights into warehouse activities enable efficient resource allocation, reduce bottlenecks, and improve order fulfillment accuracy.

As the initial step, the DT will rely on data from the current ERP system, SAP ECC, to extract real-time information on all active orders. This data will give visibility into the lifecycle of each part and show where the part resides within the system at any given time. A capability to accurately locate and track a part will deliver significant value to the organization by enabling SAC to accurately inform customers about the location of their purchased article. This issue is one of the most pressing matters in today’s network. Table 16 presents an example of a part’s lifecycle and the system involved at each stage.

Table 16: Lifecycle of a Purchase Order and corresponding systems involved.

Operation Phase	Event	Systems Involved
Pre-Warehouse	Purchase Order Created & Released	ERP
	PO Sent to Supplier	ERP
	Received → Inbound Delivery Created	ERP, WMS
	Inbound Transportation	ERP
Warehouse	Goods Receipt Posted	ERP, WMS
	Put away Completed	WMS, updates ECC
	Sales Order Created	ERP
	Outbound Delivery Created	ERP
	Picking Executed	WMS, updates ERP
	Packing	WMS, ERP
Post-Warehouse	TMS planning & carrier assignment	TMS, ERP
	Customs	Customs organization
	Loading & Post Goods Issue	ERP, WMS, TMS (event)
	In-Transit	TMS
	Billing & Freight Settlement	ERP, TMS

Furthermore, there is a desire to include external data sources, such as geopolitical happenings, weather conditions, and other factors, into the CC to enable more proactive supply chain management. While uncommon, such information could significantly improve the ability to anticipate and mitigate disruptions before they escalate. However, integrating such data into the CC could be challenging due to their unstructured nature and variability.

5.3.2 Dashboards and Spare Parts Network Use cases

Dashboards are the primary interface between the Command Centre (CC) and the users. They are the critical link, translating integrated data into actionable insights. While DT and integration enable End-to-End visibility, this visibility only creates value if it is presented in a way that supports decision-making. The dashboards can address the current challenges of fragmented systems and inconsistent information that was identified in both literature and interviews. Without an effective dashboard design, the visibility provided by the DT cannot be leveraged for decision-making.

To achieve their purpose, it was interpreted from interviews in Table 12 that simple dashboards must be designed for usability and relevance, providing the appropriate amount of information for each function to maximize the likelihood of the CC succeeding. Not too much or too little information is preferred. This is strengthened by the Customer Excellence Manager, Integrated

Network Manager APAC, and by one of the Sales Administration Mangers. The same Sales Administrator mentioned that they do not use the current Power BI dashboards since they do not fit their market, reinforcing the need for personalization. This also suggests that dashboards should not only be tailored to general functions but also adapted to the specific responsibilities and decision-making needs of individual roles. However, what qualifies as enough data depends on the function. For example, supplier-facing roles would benefit from metrics like MOQ vs EOQ, supplier performance alerts, detect & action system, and scenario tools. Customer-facing roles would not need the same metrics and instead require quick access to order status, ETA, and suggested actions to take to accelerate shipments and in turn delivery. Their dashboards should allow teams to respond promptly to customer inquiries with accurate and actionable information. Lastly, Intra-logistics roles that are more operational and responsible for execution of order, rerouting and prioritization, would benefit from real-time visibility of picking and shipping queues, alerts for high-priority orders, and prioritization logic for outbound flows based on SLA and customer impact. Customers value transparency about actions taken and updated impact.

Based on these insights and mentions by the Opimization Director at The Company, a layered dashboard architecture emerges as a potentially effective structure to meet the diverse needs of users. This analysis highlights the functional requirements and design considerations that will guide the dashboard proposals presented later in the thesis. The first layer is a network-wide dashboard that will act as general option, providing a consolidated view of the spare parts network for all functions. This alone serves as a single source of truth and includes core functionalities such as multi-parameter order lookup (SO, PO, shipment), key KPIs, etc. This layer is mainly for the functions that may not use the CC extensively but will still benefit from centralized information. Additional functionalities are presented in Table 17.

Table 17: Additional functionalities for the network-wide dashboard

Functionalities
• End-to-end flow integration • Track & Trace – Order lookup • Visibility across systems • Display KPIs • Cross-functional collaboration platform – Communication module.

The second layer built on the first layer consists of role-specific dashboards and reflects the unique responsibilities and decision-making needs of each function. Three key roles identified are supplier-facing roles (e.g., Supply Network Specialists), Intra-logistics roles (e.g. Replenishment and SOS), and customer-facing roles (e.g., Sales Administration Managers). Supplier-facing roles require tools for proactive supplier management. Intra-logistics roles need dashboards that support operational agility, for example providing real-time insights into warehouse activities and prioritization logic for urgent shipments. Customer-facing roles, however, require dashboards that can simplify communication and offer quick access to order status, delay reasons, etc. These role-specific dashboards ensure that each function receives the appropriate and right level of detail that can enable fast and informed actions. The functionalities for the three key roles are presented in Table 18 and were selected by the authors based on a synthesis of the empirical findings from the interviews and survery results. The functionalities were validated through a workshop with stakeholders at The Company.

Table 18: Functionalities for role-specific dashboards

Role	Functionalities
Supplier-Facing	• Alerts related to supplier performance and disruptions • Dedicated supplier tabs for quick access to relevant data • Prioritization logic for inbound shipments and critical materials • Scenario planning tools (e.g., MOQ vs EOQ, lead-time trade-offs) • Supplier performance KPIs and compliance tracking
Intra-logistics	• Scenario simulation • Alerts for urgent or high-priority orders requiring immediate action • Real-time visibility of picking, packaging, and shipping queues • Prioritization logic for outbound shipments based on SLA, customer impact, delay risk, etc.
Customer-Facing	• List of critical orders with prioritization reasons • Recommended actions tab (e.g., notify customers, notify another function) • Integrated communication options • Order lines impacted • Categorization by market and contract type • Delay reason visibility linked to fault codes • Forecast-based risk indicators for potential delays • Alerts from customs holds or missing documents

The proposed dashboard architecture should follow this layered approach to ensure end-to-end visibility and core functionalities, complemented by role-specific dashboards. A single source of truth is the goal, and this design aligns with The Company's ambition by integrating data from relevant sources into a unified platform. Linking the data sources (ECC, WMS, TMS, and external sources) will in turn enable end-to-end visibility and contextual decision support across the spare parts network. In addition, customers should also be provided with a simple dashboard that allows them to accurately track their purchased goods and active orders, ensuring transparency and reducing the need for manual status inquiries for the SAC teams.

5.4 Delays

Through the empirical findings, delays emerged as the second main point alongside visibility. Several KPIs are impacted if delays occur and not managed appropriately. For example, delays lead to a direct decline in Service Levels as fewer lines are delivered on time, and in turn create negative downstream effects on Customer Excellence (CX) when delay notifications are late, unclear, or simply reactive. The Customer Excellence Manager revealed that so far in 2025, 59% of customers provided no feedback (which is interpreted internally as “no complaints”), while 9% explicitly report dissatisfaction due to lack of delay notifications. This highlights that the issue concerns the communication gap rather than only the physical lateness of the order. In addition, delays extend overall lead-times to customers, which is the most frequent complaints from customers. Approximately 10% of customers consider lead-time too long, making this a critical dimension of perceived performance. However, delays are not isolated incidents as they cascade through the supply chain and affect multiple nodes. Much like the phases mentioned in Table 16, the empirical findings and order timeline suggest that delays can be grouped into three dominant families: Supplier delays, Warehouse delays, and transport delays. Each sub-category of delays has distinct root causes that will be further analyzed.

5.4.1 Supplier Delay

Supplier delays occur when confirmed incoming delivery dates slip, in turn creating availability shortfalls and can cascade issues downstream. The slips can, for example, be caused by errors in production, production capacity constraints, lead-time variability, or inter-supplier dependencies where one supplier relies on another for critical components. Other drivers include high MOQs, quality validation bottlenecks, and system fragmentation that slows detection of confirmation changes.

When a supplier is delayed, the immediate result is reduced material availability at the distribution center, which blocks order fulfillment and can prevent complete shipments if those parts do not have sufficient safety stock. This not only increases the likelihood of missed service levels but also extends overall lead-times to customers. In practice, supplier delays ripple through planning, production, and logistics, which can in turn force the spare parts network to turn to reactive measures, adding cost complexity. According to the Distribution Center Manager in Brazil, availability shortfalls are driven mainly by supplier delay and system issues, reinforcing the need for early detection and proactive management.

Supplier delay refers to any delay from a supplier or any other hold-up. Most importantly, customer-facing functions should be notified to pass this information on to the impacted customer.

5.4.2 Warehouse Delay

Warehouse delays occur within internal operations, from the moment goods are receipt, to picking, packing, and shipping. While capacity constraints were mentioned, interview highlighted additional drivers such as inventory inaccuracies and outbound being a bottleneck. According to the World Class Manufacturing Manager, these issues can lead to missed picking waves and postponed shipments, where goods are ready to be shipped but not dispatched on time due to internal congestion or other internal issues. The World Class Manager mentioned that simple human errors could also play a role, including miss-picks, incorrect prioritization, and reliance on manual coordination when system support is lacking.

Several interviewees as can be seen in Appendix D pointed to fragmented system support as one of the main points to warehouse delays. The DC Manager in Brazil mentioned that inventory discrepancies and missing bin data frequently forces the staff to rely on spreadsheets and manual workarounds. The Global Planning & Data Experts too highlighted this, as confirmation changes from suppliers are not automatically generated, requiring manual follow-up and spreadsheet tracking.

5.4.3 Logistics Delay

Logistics delay typically occurs after goods leave the warehouse and are often linked to carrier performance issues, customs clearance problems, or external disruptions such as strikes or severe weather. Customs clearance problems often arise due to documentation errors, such as missing HS code or incorrect country-of-origin data. These delays will impact on the entire shipment and can escalate longer lead-times for parts not under inspection or ones that have correct documentation. Therefore, one item with incorrect documentation can turn a minor disruption into significant SLA breaches. External disruptions, such as natural disasters or strikes, are difficult to predict or forecast. However, by engaging alternative carriers, having agreements with them and the ability to active them quickly can reduce the impact when such events occur. By proactively communicating with the customer and providing updates on the status of their order, the negative perception of delays can be reduced. Even if a part is late, regular and transparent updates from the spare parts network would help maintain trust and demonstrate reliability.

5.5 Root-cause analysis

To understand the underlying causes of delays in the spare parts network, a root-cause analysis was conducted using both interview insights, company data and literature. The analysis revealed that the causes of delays have a huge variation and can be divided into a wide range of sub-problems across different areas of the supply chain. These sub-problems vary in nature and impact, but collectively contribute to reduced service levels, longer lead times, and diminished customer satisfaction.

5.5.1 Root Causes

The sub-problems are categorized into five mains areas as can be seen in Figure 20: Supplier, Transport, Customs, Warehouse, and Data/Systems. Each category includes specific causes that were frequently mentioned during interviews and or supported by literature. Descriptions for each category are presented in Table 19. The causes were created by the authors based on interpretations from the empirical findings.

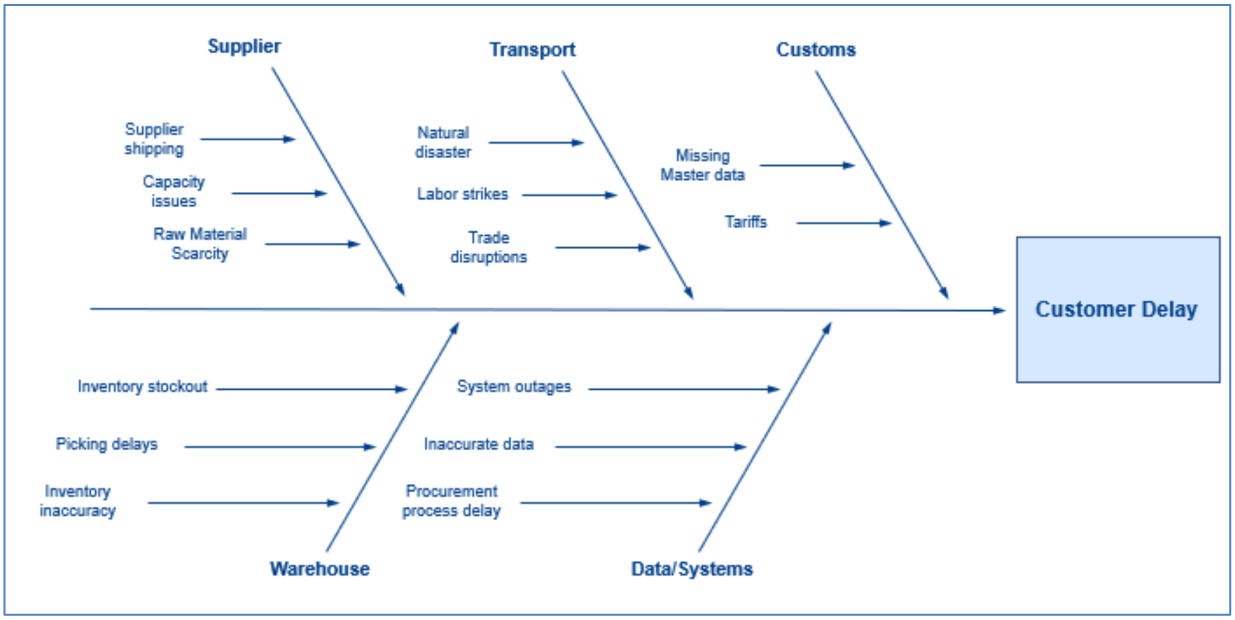

Figure 20: Causes of customer delays categorized by source

Table 19: Description of causes mentioned in Root-Causes Analysis

Category	Cause	Description
Supplier Related Causes	Supplier shipping	Late dispatches or missed shipping windows from suppliers can disrupt planned lead times.
	Capacity Constraints	Limited production capacity or overbooked schedules at suppliers lead to extended lead times and inability to meet urgent demand.
	Raw Material Scarcity	Shortages of critical raw materials can halt production, causing delays that ripple through the supply network.
Transport Related Causes	Natural Disasters	Events such as floods, hurricanes, or earthquakes can disrupt transportation routes and halt shipments
	Labor Strikes	Strikes among transport workers or port staff can lead to severe delays in moving goods across regions.
	Trade disruptions	Geopolitical tensions, sanctions, or sudden regulatory changes can block or slow down cross-border flows
Customs Related Causes	Missing Master Data	Incomplete or incorrect documentation often results in customs clearance delays
	Tariffs and Regulatory changes	Sudden changes in tariffs structures or compliance requirements can cause rework and hold-ups at customs checkpoints
Warehouse Related Causes	Inventory Stockouts	Lack of available stock for critical parts prevents timely order fulfillment.
	Picking Delays	Inefficient picking processes or capacity bottlenecks in outbound operations can postpone shipments.
	Inventory Inaccuracy	Discrepancies between system records and physical stock lead to errors and additional time spent resolving issues.
Data/systems Related Causes	System outages	Downtime in ERP, WMS, or TMS systems disrupt visibility and coordination, delaying operational decisions.
	Inaccurate Data	Poor data quality, such as incorrect lead times or missing attributes, results in flawed planning and reactive firefighting.
	Procurement Process Delays	Manual workflows and lack of automation in procurement slow down order creation and supplier confirmations.

5.5.2 Pareto Analysis

To better understand the most frequent causes of delays in the spare parts network, a Pareto analysis was conducted using available discrepancy and damage code data. While no single definitive source exists that explicitly links each delay to its root cause, the combined data from discrepancy reports, ticketing systems, and non-conformity records provides a reliable foundation for identifying patterns.

A discrepancy, as defined by The Company, refers to any deviation from the expected order, including: Receiving more or fewer pieces than expected, receiving a different part than ordered, and transport damage. From January to August 2025, a total of 1596 discrepancy cases were recorded of them 92% were outbound related, the rest were either transport or inbound related. This confirms that outbound processes are the primary bottleneck in the Main DC, which aligns with interview insights from interviewee C. The Pareto chart presented in Figure 21 and the damage code data in Table 20 reveal that five damage codes account for 86% of all discrepancies:

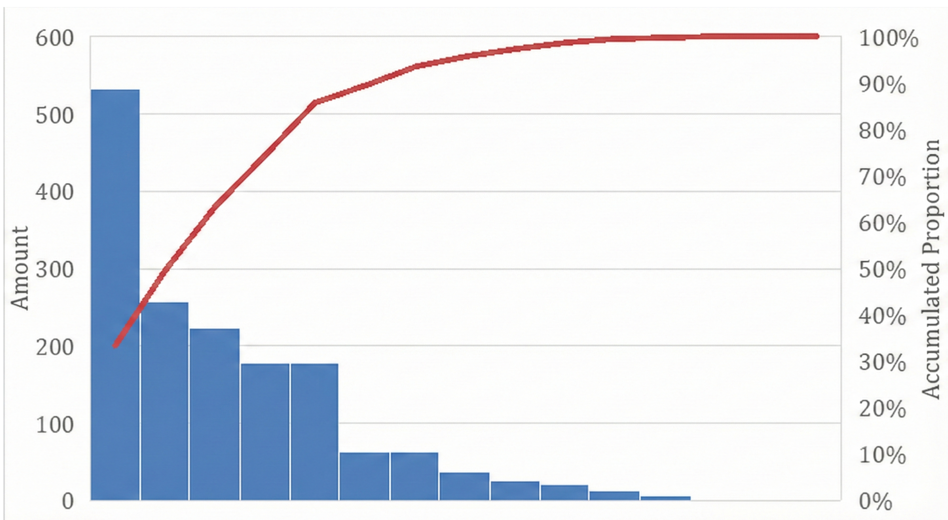

Figure 21: Pareto Chart for frequency of Discrepancies by Damage Code Texts between January 2025 to August 2025.

Table 20: Full damage code texts and number of times mentioned between January 2025 – August 2025.

Damage Code	YTD Aug 2025
Missing article (partial)	**533**
Received different part than ordered	**257**
Missing article (completely)	**223**
Received too many/surplus	**177**
Transport damage	**177**
Damaged part	63
Picking error related to Rec. goods	62
Lost Shipment	37
The part does not belong to order/shipment	26
Part not complete	20
Supplier related disc.-wrong item	13
Consolidation error	6

Compression	1
Documentation Error	1
Error in outbound	0

Out of the total 15 damage categories, these top five represent approximately 33% of the categories but contribute to over 80% of the total discrepancy volume, illustrating the classic Pareto principle: a small number of causes are responsible for most of the problems. This insight is critical for prioritizing improvement efforts. By focusing on these five categories, The Company can address the bulk of discrepancy-related relays with relatively targeted interventions. For example, improving outbound picking accuracy and packaging integrity could significantly reduce missing and damaged articles. Of the 5 most common discrepancies, 4 could be mitigated by increased visibility. Additionally, Figure 22 categorizes ticket reasons. Most tickets are raised due to price/supplier data gaps or delivery time changes, reinforcing the need for better visibility and proactive communication.

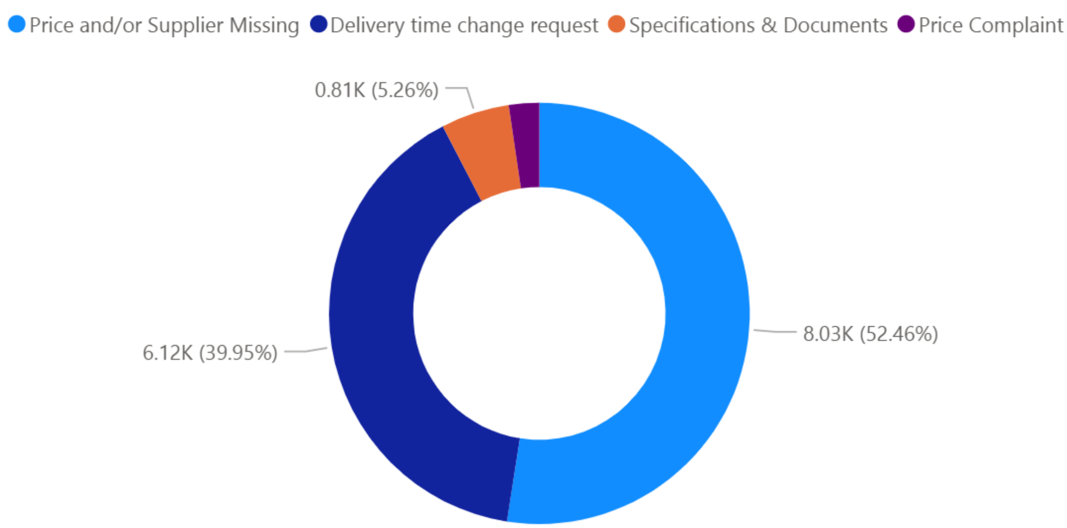

Figure 22: Pie chart for part ticket categories for all cases between January – August 2025

The combination of the Pareto analysis, and the ticket analysis identifies two distinct root causes. The first can be seen in Figure 21, being a physical bottleneck in outbound warehouse processes (92% of discrepancies). The second root cause is seen in Figure 22 where 92.41% of all tickets raised are caused by information gaps. These results demonstrate that the network is hindered by both execution errors and data ambiguity, which create uncertainties and force employees into ad hoc management. By implementing a Digital Twin, the company can create the transparency necessary to track flows and expose these pre-existing vulnerabilities. Ultimately, by addressing these dual root causes, The Company can depend on proactive practices instead of reactive management.

5.6 Detect & Action/ Solutions

This section presents the functional solutions enabled by Digital Twin (DT) technology, structured according to the Detect and Action phases of the SDAR framework. The following subsections explore the desired detections, the role of machines learning, the specific actions or solutions needed to mitigate disruptions, and lastly the placement of the solutions in the Value-To-Effort matrix.

5.6.1 Detect

One of the core capabilities of a DT is its ability to surveil and detect deviations, disruptions, and emerging risks within the supply chain. The aligns with the second step of the SDAR framework introduced in section 2.4, which emphasizes the importance of detection following surveillance. The Company's spare parts network has made significant progress in the first two stages of the Digital Supply Chain Surveillance practice, having implemented data collection and processing, and some data analysis. The next step is to translate this into actionable insights, which is still in its infancy. This is where the DT can bring substantial value.

The spare parts network already has a clear understanding of what entities and activities it wants to surveil. These are primarily endogenous data sources such as ERP, WMS, and TMS systems. In the context of the Digital Twin Architecture (Figure 17), these data sources represent the Data Layer. The foundational monitored data includes the connection between Sales Orders (SO), Purchase Orders (PO), and shipments, which together form the backbone of the supply chain flow. Additional data points from warehouse operations, transport events, and master data attributes are also relevant and should be integrated into the surveillance layer. While exogenous data (for example weather, geopolitical events), could enhance detection capabilities, it is according to the Digitalization Manager, not prioritized at the current stage of DT development. From the empirical findings, automatic detection of deviations was consistently mentioned as a desired capability in the survey, seen in Appendix H. Table 21 presents interviewees need in a system and what can be identified.

Table 21: Detection examples from the survey

Detection
Late supplier deliveries
Goods not handled within 24 hours
Overload in picking areas
Missing master data
Sudden spikes in demand
Significant delays in shipments to customers

These issues, if detected early, can be mitigated before they escalate into problems for the customer. As highlighted during interviews with the Planning & Inventory Optimization Manager, if if a PO is predicted to be delayed, the system could suggest reordering from an alternative supplier which is enabled by the new planning system's dual sourcing capability. Similarly, empirical findings from the Sales Administration Center (SAC) and Optimization Director identified that shipments are often held in customs due to missing documentation. Here, a DT could proactively alert teams to submit paperwork before the shipment reaches the border. To detect issues efficiently, the analysis suggest that detailed data and understanding of the context are essential. Interview the te Replenishment Manager indicate that simply flagging all orders that exceed average delivery times is insufficient and may lead to “alert fatigue”.

In summary, the detect capability of the DT is not just about identifying problems, it’s about doing so early, accurately, and contextually, enabling the organization to move from reactive firefighting to proactive risk management. This capability lays the foundation for the next step in the SDAR framework: Action, which can be explored in Section 5.6.3.

5.6.2 Applied Machine Learning for detection

To proactively manage disruptions in the spare parts supply network, machine learning (ML) offers powerful capabilities for early detection and forecasting. By leveraging historical and real-time data, ML models can identify patterns, predict delays, and support decision-making before issues escalate into customer-facing problems.

One of the most critical applications of ML in the Digital Twin (DT) is predicting delay risk. A delay to the customer is often the result of earlier disruptions in the supply chain as was examined earlier in the root-cause analysis in 5.5. If these upstream delays can be predicted early, DT can simulate their consequences and recommend mitigative actions before the customer is affected. For example, if a purchase order is predicted to be late, the system could suggest alternative sourcing options or prioritize the order in ticking and transport. Similarly, if picking capacity is forecasted to be insufficient for the upcoming workload, the system could recommend staffing adjustments or reallocation of resources.

While ML models can provide high accuracy, their effectiveness depends on the quality and detail level of the data input. (Steinberg et al., 2023) For low-volume, high-variety products as is the case for The Company, which can be seen in Figure 23, prediction is more difficult. However, as shown in the study by Steinberg et al. (2023), even in such environments, delay prediction is feasible with sufficient ERP data.

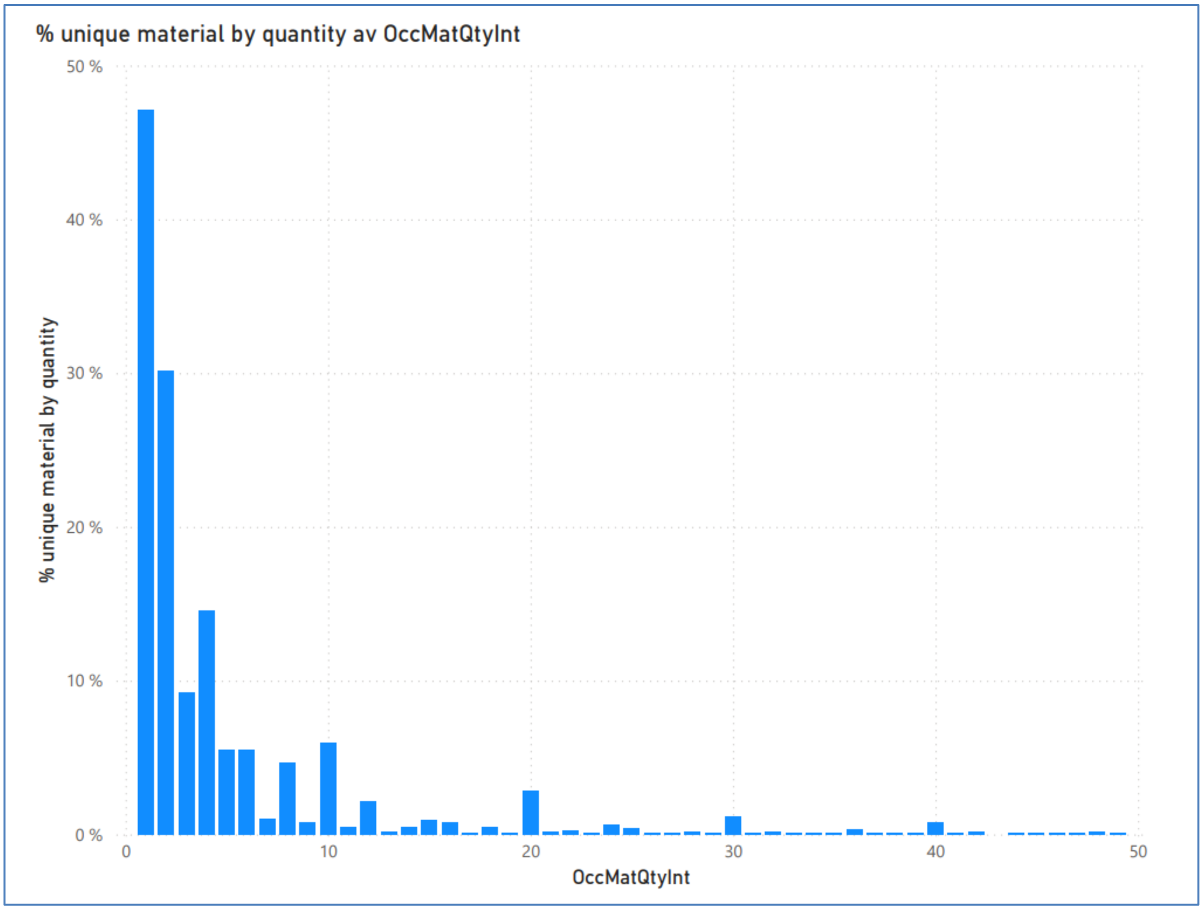

Figure 23: This Figure illustrates the frequency of product orders throughout 2024. The y-axis represents the proportion of products, while the x-axis shows the number of times they were ordered.

To maximize value, predictions must be made early enough in the supply chain to allow for meaningful interventions. This aligns with the SDAR framework, where detection is followed by action. ML models can serve as the foundation for automated detection systems, which enable proactive decision-making and improved customer satisfaction.

5.6.3 Action

Once a deviation or potential disruption is detected in the spare parts network, the next step in the SDAR framework is to identify the areas or functions that may be affected and need to be alerted. These roles will be provided with options for supported decision-making (Brintrup et al., 2022). The decision-support system is based on combining simulation, optimization, and data analytics together. Using simulation after a disruption is detected, the DT can help forecast the disruptions projected impact. This process can be seen in Figure 24.

Figure 24: Decision-support flow within the SDAR framework

A DSCT will utilize data of the physical SC to suggest objective decisions (Ivanov et al., 2019). Interviews confirm a desire and need recommended actions to take when operational decisions need to be made to mitigate or avoid risks. The ambition is to move beyond reactive detection toward proactive risk management and incorporate "what-if" questions such as:

- What happens if a sales order is delayed?
- What if a shipment is rerouted?
- How does changing warehouse capacity affect lead-time and costs?

Using predictive analytics combined with simulation, these questions can be answered to reveal trade-offs between the different suggested actions. Trade-offs regarding parameters such as cost, lead-time, CO_2 emission, and service level. This approach enables informed decisions, balances trade-offs, and ultimately improves customer experience while supporting sustainability and cost-efficiency. The examples presented in Table 22 were selected from a broader list of potential use cases previously seen in Table 14. These are selected because they represent high-priority "pain points" identified during the mapping of challenges in the spare parts network.

Table 22: Detections, their corresponding action and description from interviews

Detect	Action	Description
High-priority customer issue	Escalate to relevant team and flag in dashboard with resolution timer	When an issue is detected on an order linked to a high-priority customer, such as a customer with contract agreement, the system escalates the case to the responsible team based on the nature of the issue. It should also visually flag the order on the dashboard with a countdown timer indicating the time elapsed since the goods have remained unhandled, up to the 24-hour threshold. This would ensure visibility and prioritization, reducing the risk of Service Level Agreement breach and improved customer satisfaction.
Planned order at risk of delay	Notify planning team and suggest alternative dispatch options.	When an order is likely to miss planned delivery dates, the system identifies it based on real-time data (e.g. lead time, transport delays, stock shortages) and alerts the planning team. It will then propose alternatives such as splitting deliveries or sourcing from alternate warehouses to minimize impact.
Repeated issues with	Flag for root cause analysis and	The system tracks recurring disruptions linked to certain customers or SKUs. The system identifies flags if they occur and

specific customers or product	improvement initiative.	suggests a structured root cause analysis dedicated to the specific issue to establish long-term corrective actions. This approach aims to improve underlying processes and ensure that mitigation strategies outlined in the playbook are effectively implemented and continuously refined.
Late priority order	Ability to notify resource manager or reroute work	When a priority order is delayed, the system should send alerts to relevant managers and propose recommendations on procedure or to act. Recommendations such as propose rerouting tasks or reallocating capacity to meet deadlines. This could minimize downstream impact.
Forecasted warehouse congestions	Notify relevant team	Using predictive analytics and simulation, a DT could enable the CC to anticipate periods where inbound and outbound flows exceed warehouse capacity within an upcoming period. It could then alert the teams responsible to recommend proactive actions, such as reallocating labor. These actions aim to prevent bottlenecks and maintain a stable throughput.

A capability that would be beneficial in the CC based on interpretation from the interviews, and their needs for a guideline once issues are detected, is the integration of a playbook. The playbook would serve as a structured base of predefined actions for reoccurring disruption types. The idea is to have an open reference that allows teams to browse previous actions, understand the impact those actions had, and see who executed them. This would ensure consistency across the network and facilitate knowledge sharing across regions and teams. Instead of leaving decision makers in the dark, the playbook provides transparency on how similar situations were handled before. Rather than relying on impulses when operational choices must be made under pressure, the playbook offers clear guidance based on historical responses to specific alerts. These would only be recommendations, not rigid rules, and can be adapted to context. Interviews revealed uncertainty about who should act on alerts, and SAC emphasized the need for standardized responses.

5.6.4 Value-To-Effort

To determine the implementation priorities for the proposed Digital Twin (DT) capabilities, a Value-To-Effort analysis was performed. As described in the methodology (section 3.6), this analysis serves as the final synthesis of the study, bridging the gap between theoretical potential and organizational reality. This analysis evaluates each capability along two dimensions: the expected value in terms of improved visibility, responsiveness, and customer experience, and the relative effort required for implementation, considering data integration, system development, and organizational readiness. While precise quantification of effort is challenging, the assessment reflects the complexity of data structuring and the maturity of existing infrastructure. The ten capabilities evaluated in this section (see Table 23) were derived from the thematical analysis of the interviews and surveys. Specifically, they represent a refinement of the detections and actions identified in Table 22, the wider list in Table 13, and desired capabilities seen in Table 12. These ten were selected because they were the most frequently mentioned "pain points" and desired future outcome by the participants.

Table 23: Core Digital Twin Capabilities derived from the case study

Number	Capability
1	End-to-end Order Visibility
2	Role-adapted and customer Dashboards
3	Threshold based detection
4	Delay Prediction
5	Action recommendations
6	Prioritization
7	Missing Master Data Detection
8	Exogenous Risk Detection
9	Scenario Simulation
10	Automated Decision Making

The analysis reveals that the end-to-end order visibility (1), achieved through ERP, TMS, and WMS integration, represents a high-value, low-effort initiative. Most foundational work has already been completed. This foundation resemble a traditional visualization system rather that a full DT and can be classified here as Digital Shadow. This capability serves as the backbone for subsequent functionalities. Building on this, role-adapted dashboards (2) and threshold-based detection (3) offer high value with minimal effort by enabling faster and more proactive responses.

In contrast, the development of delay prediction (4), which utilizes machine-learning models for forecasting, demands significant effort due to data preparation and algorithm testing yet promises high value through enhanced risk management. Action recommendations (5), which provide prescriptive decision support through SDAR-aligned playbooks, offers substantial benefits for consistency and speed of resolution. These recommendations are critical for ensuring that detections lead to coordinated responses across the network. A prioritization (6) engine based on weighted rules provides moderate value and effort, specifically improving fairness in stock allocation and reducing service level agreement breaches.

Capabilities like missing master data detection (7) and exogenous risk detection (8) present very high implementation efforts. Detecting incomplete customs documentation through AI agents is technologically complex, and while it mitigates delays, its overall impact is moderate. Similarly, incorporating external risk feeds such as weather or geopolitical disruptions requires irregular data handling and integration, resulting in high effort for medium value. Scenario simulation (9) capabilities, though useful for strategic planning, deliver limited operational benefits and involve extensive modeling of a complex spare parts network. Finally, autonomous decision-making through AI agents represents a long-term vision with immense potential value but equally immense effort, positioning it as an aspirational goal rather than an immediate priority. The difficulty of AI agents specifically for the spare parts network AI agents are often built using reinforcement learning based on profit however the spare parts network is driven by customer experience, which is hard to quantify, simulation would also be an enabler of automated decision making (10).

In Figure 25 the value-to-effort matrix can be seen which is based on the impact-to-effort matrix presented in the literature review. The capabilities mentioned in Table 23 are mapped out according to their value and effort relative to each other. Compared to the matrix impact to effort matrix, impact has been changed to value to better fit this study, and the axes are now low, medium, high, and very high to give a better range.

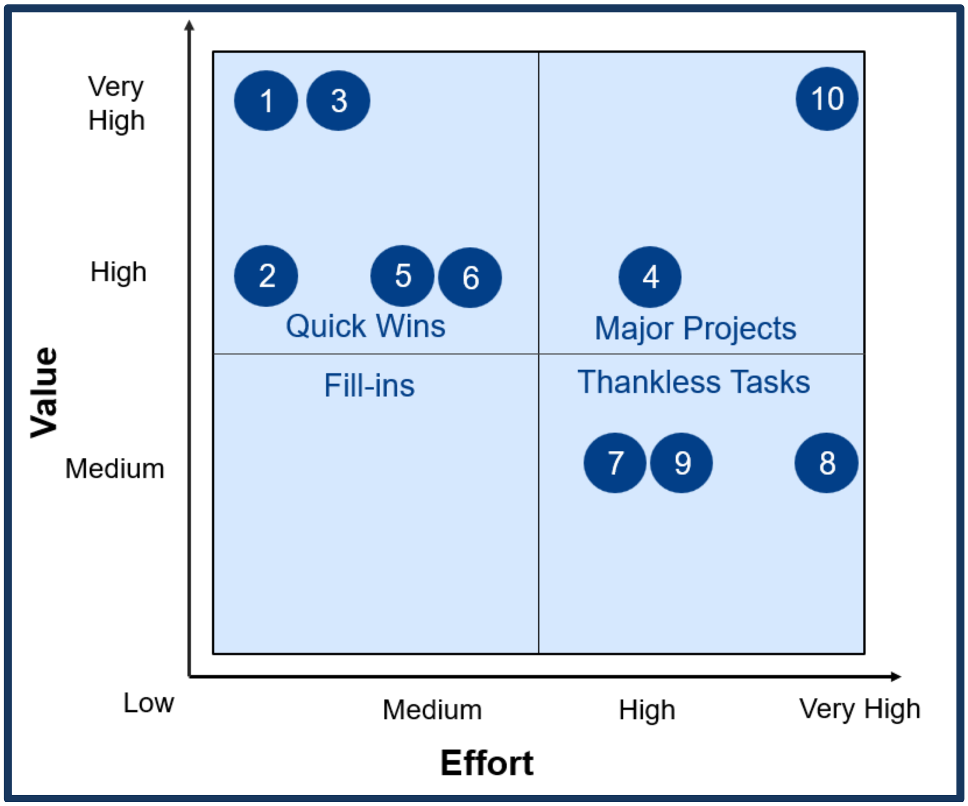

Figure 25: Value-to-Effort matrix with solutions mapped out relative to each other

The analysis shows that end-to-end order visibility is among the most valuable and the least complex capabilities to implement. Together with role-adapted dashboards, threshold-based detection, and action recommendations, these represent the quick wins of the DT initiative. Prioritization was also placed in quick wins as it was specifically requested by employees, offers clear operational benefits, and requires only moderate effort to implement. They deliver immediate benefits and make the Command Centre worthwhile from the start, creating short-term value and meeting the expectations of employees who see these features as essential. These capabilities do not fundamentally change how the spare parts network operates today; instead, they enhance current processes and enable smoother operations. They also act as enablers for the ongoing network transformation and future DT functionalities. For example, action recommendations will form the basis for automated decision-making, while end-to-end visibility will generate structed historical data that can later support machine learning models which are hindered by the unstructured nature of existing data.

Delay prediction and automated decision-making fall into the category of major projects. Both require significant effort and technical sophistication but have the potential to transform the spare parts network. Delay prediction enables proactive risk management by anticipating delays before they occur, while automated decision-making could fundamentally reshape the network's structure and operating model.

Finally, missing master data detection, exogenous risk detection, and scenario simulation are considered "Thankless tasks" in the current context. These solutions demand considerable resources but provide limited immediate value, making them unsuitable for early implementation. The positioning of these solutions, for example scenario simulation, was the result of a process when adressing notable differences in rankings from different functions. E.g. while the Planning and Optimization Manager viewed the solution as "Very Important", one Sales Administrations manager ranked it significantly lower and instead prioritizing "Real-Time Visibility" to handle current customer requests. In weighing the conflicting perspectives, immediate operational demands shared by majority of functional roles were prioritized and technical constraints identified by the Digitalization Manager. However, the relevance of the solutions in the "Thankless tasks" section may increase as the DT evolves and dependencies shift. For instance, scenario simulation may not justify its cost on its own, but if it becomes a prerequisite for automated decision-making, its strategic importance will rise. At present, however, these capabilities remain low-value and high-effort, and other initiatives should take priority.

5.7 Implementation Roadmap

Based on the Value-to-Effort matrix and the SDAR framework analyzed in previous sections, the capabilities required for the spare parts network can be organized into three implementation phases and can be seen in Table 24. This roadmap ensures scalability and addresses the immediate need for a unified order timeline before moving toward advanced autonomous systems.

Table 24: Recommendations for digital twin capabilities, divided into implementation phases

Phases	Capability	Description
Phase 1	End-To-End Order Visibility	Combine ECC, WMS, and TMS data for a unified tracking of SOs, POs, and shipments.
	Role-Based Dashboards	Create tailored dashboards for specific roles, responsibilities, and customers with real-time insights.
	Threshold-Based Detection	Implement rule-based alerts for deviations such as extended lead times or delays.
	Action Recommendation	Provide prescriptive suggestions for corrective actions based on SDAR logic
Phase 2	Functional Prioritization Algorithm	Implement prioritization algorithms for tasks and orders across functions to improve alignment with SLA.
	Scenario Simulation	Enable simulation of scenarios to support strategic decision-making.
	Exogenous Risk Detection	Integrate external risk feeds (e.g. weather, geopolitics) for proactive alerts
	Master Data Monitoring	Monitor and flag incomplete master data to reduce processing errors
Phase 3	Delay Prediction	ML-driven forecasting of supplier delays and network congestion using historical and real-time data.
	Automated Decision-Making	Enable fully autonomous execution of decisions once system reliability is proven.

5.7.1 Phase 1 (Quick Wins)

The first phase focuses on capturing the Quick Wins for The Company. Capabilities that deliver high value relative to the effort required. These are either considered low-hanging fruits or areas where The Company has already made progress. The priority is to establish visibility and basic decision support. This begins by integrating the existing ERP, WMS, and TMS systems to provide visibility from the moment a Sales Order is created until the Purchase Order is released. Combined with role-adapted dashboards, these capabilities provide a unified view, in turn reducing fragmentation and enabling real-time insights. The visualization can be made by connecting Power BI to SAP HANA using DirectQuery for real-time dashboards. To ensure scalability and usability, the DT and supporting information systems should be planned carefully by selecting the most relevant data sources and identifying where DTs can bring the most value. It is better to start small and on a restricted scale, then scale up (Moshood et al., 2021). Beginning with the network overview and then focusing on the most relevant functions. Threshold-based detection and action recommendation complement this by adding proactive alerting and prescriptive guidance to improve responsiveness. The goal of this system is to detect problems and then suggest an action, based on the SDAR framework. For example, if missing master data is identified, the system can detect it and thereafter send alerts to relevant functions to address the issue. Together, these capabilities will create the data backbone for future enhancements.

5.7.2 Phase 2 (Advanced decision-support)

The second phase introduces more advanced features that require more effort but bring value by enhancing the decision-making process. The capabilities include a network-wide prioritization algorithm, scenario simulation, exogenous risk detection, and master data monitoring, A prioritization algorithm ensures fair and impact-driven order handling which addresses current gaps in contextual prioritization. For example, prioritization can be based on weight criteria such as contractual obligations or potential impact on service levels. Scenario simulation will enable "what-if" analysis, while exogenous risk detection and master data monitoring can strengthen resilience and operational robustness by reducing errors and anticipate external disruptions. These capabilities will collectively improve alignment across functions, break down existing silos, and support proactive risk management.

5.7.3 Phase 3 (Strategic vision)

The final phase focuses on advanced and strategic capabilities that demand high effort but offer transformative potential. Delay prediction, powered by machine learning and AI, will help forecast potential disruptions before they occur. Automated decision-making is positioned as an optional, future-oriented capability that can be introduced for recurring, low-risk decisions once system reliability and trust are established. While these capabilities demand high effort and organizational readiness, they can theoretically (Ivanov and Gusikhin, 2025) deliver substantial value by providing decision support, improving responsiveness, and ultimately enhance customer satisfaction, though interviewees viewed automated decision-making as less important.

5.8 Validation of Capabilities

To validate if our understanding of the desired capabilities were correct, a workshop with the management team of the spare parts network was held where the results of the thesis were first presented and then discussed by the members of the workshop. The workshop was attended by the Digitalization manager, Customer Service Excellence manager, Director for optimization, Director for planning and quality and the Vice President for the supply network. The solutions outlined in the analysis and resulting from the value to effort analysis were validated by the attendees of the workshop and the placement on the value to effort matrix was also validated. It was confirmed during the workshop that the capabilities with both the effort and value associated with them was aligned with the expectations from The Company.

5.9 Discussion

5.9.1 Barriers / Challenges

Implementation of a DT promises significant benefits, but it is not without obstacles. Several areas and barriers need to be addressed to ensure successful integration. These barriers are gathered from the interviews, what literature says, and personal interpretations and speculations. One potential barrier relates to the user access and associated costs. During the interview with the Global Planning & Data Experts, concerns were raised about the high licensing fees for full access to the new planning system. Although this may not become a major issue if access costs are included in the new planning system and the Command Centre (CC) will be included in its features, it still raises questions about who should have what level of access. Defining the access tiers and included responsibilities are essential to be established to avoid unnecessary expenses.

An additional challenge is regarding the ticketing system and is brought up by the Replenishment. The CC will be beneficial for the SAC teams. One of their responsibilities is to raise tickets from customers. If the CC makes it too easy to raise tickets, there is a risk that ticket volume will surge uncontrollably. It could in turn erode prioritization. Without clear thresholds, the system could be overloaded with issues that are not considered critical, and in turn reduces the effectiveness.

Ownership and responsibility are another concern that can't be neglected. The CC must establish clear routing of issues to the appropriate roles, whether it is regarding transport, supplier management, or planning. This was highlighted by the Manager for planning and inventory optimization. Without this clarity, accountability gaps will remain and suggested actions for detected issues can't be delegated. Then, the benefits of centralized visibility will disappear. Closely related is the question of oversight, where the Director for planning & quality emphasized the concern about who should manage the CC. Should there be a single role responsible for the entire platform, or should each function appoint a dedicated owner for its respective area? An owner who receives all detected issues and suggested actions. If only one individual is assigned for overall responsibility, that person must have cross-functional knowledge which is most likely only gained through specific work experience and difficult to develop internally. Another challenge that is important to consider is change management and cultural resistance. While the DT may not drastically alter daily routines, the CC might. It could introduce new workflows and structures. Employees might resist these changes, especially if they perceive the system as complex or threatening to established routines.

Furthermore, it is important to distinguish between the CC and the Planning system functionalities. Several features could be borderline between the two, as expressed in the interview with one of the Supply Network Specialists. Without clear boundaries, there is a risk of duplication, confusion regarding responsibilities, and inefficiencies.

Having robust cybersecurity when implementing a DT is crucial according to Hearn and Rix (2019) and the Digital Twin engineer that was interviewed. The benefits of DTs and other smart technologies are plenty, and together with it several vulnerabilities, such as security breaches and IP theft (Hearn and Rix, 2019). It is important that not everyone can easily access the data provided by Digital Twin. According to the Digital Twin Engineer, basic security needs to be incorporated. One way could be with the use of signatures or keys to protect sensitive data, ensure the right people gain access to the system and manage the data streams.

5.9.2 Disparity Between Vision and Reality

Digital Twins (DTs) is not merely a buzzword, but it is a concept that has, according to the authors, been occasionally overused and positioned within the technology hype cycle. Based on the author's interpretation, The Company's vision of a DT resembles a centralized data storage that unites and connects information from multiple sources in real-time. On top of this storage foundation, layers of algorithms, thresholds, and advanced capabilities, such as machine learning, can be applied. While a system like that may be interpreted and labeled as a DT, its scope differs from the more comprehensive definitions found in literature. The Company's ambition is to develop a near real-time data platform that connects SOs and POs. While this approach may align with certain aspects of a Digital Supply Chain Twin (DSCT), it does not fully capture the whole picture. The literature definition for a DSCT also incorporates simulation capabilities and "a model that can always represent the network state in real-time for any given moment (…)". Simulation capabilities are much more central to the standard DT, while deemed as low value by The Company. Furthermore, research on DTs in supply chains at a network level is less extensive compared to asset-level applications, where IoT technology, CAD-models, sensors, RFID, and other real-time tracking technologies are used to create an accurate representation of a physical asset. These technologies enable precise location tracking and customer-facing visibility. However, implementing a similar sensor-based solution across the entire supply network would require significant resources and might not justify the expected value gained.

Ultimately, the distinction lies in the scope and functionality. DTs are designed to monitor, simulate, and optimize performance to drive sustainability, operational efficiency, and data-drive decision-making. While these benefits are riveting, most tangible applications of DTs have emerged outside supply chain contexts. Therefore, any implementation must prove performance improvements over what existing processes already can achieve, to justify the high recurring costs associated with DT and supportive technologies.

6. CONCLUSIONS

The last chapter of the thesis aims to answer the research questions, summarize the findings from the study and provide a recommendation. Furthermore, it discusses the contribution to theory and to the case company. Finally, it addresses the limitations of the research and future research that could contribute to The Company and academia.

The purpose of this thesis has been to investigate how a Digital Twin can enable end-to-end visibility, improve decision-making in the spare parts network, and serve as a cross-functional platform that fosters collaboration and breaks down silos. The focus originates from the silos caused by limited end-to-end visibility, reactive decision-making, and insufficient cross-functional collaboration. This was studied through a case-study at the case company, where qualitative data was gathered through interviews with stakeholders connected to the spare parts network or relevant ongoing projects. A broad set of interviewees were selected to ensure a comprehensive understanding and capture multiple perspectives on the network and its pain points. Complementary quantitative data was gathered to support and triangulate the qualitative findings. An analysis of the data was conducted using thematical analysis, with iterative comparisons made against the literature review to strengthen the credibility of the findings. The following section presents the findings derived from the research questions, which were designed to guide and address the purpose.

6.1 Answers to Research Questions

6.1.1 Research Question 1

RQ1: *What is the structure of the spare parts network and what current challenges exist regarding end-to-end visibility and cross-functional collaboration?*

The spare parts network at The Company is built on several interconnected functions with the goal of supporting a global customer base. Yet its complexity introduces several challenges. While the network includes key nodes such as suppliers, DCs, MUs, the coordination between entities is often hindered by fragmented systems and siloed processes. The functions within the network are Planning, Quality, Operations, Transport & Logistics, Sales Administration Centers, Customer Excellence, and Optimization. These operate with limited visibility into the broader flows, which restricts the ability to make proactive and informed decisions.

A central challenge identified is the occurrence of delays throughout the network, which significantly affects customer satisfaction. These delays stem from multiple sources. One of the most prominent sources is the lack of end-to-end visibility, where each function tends to rely on its own priorities and data without connection to the bigger picture. This fragmentation makes it difficult to anticipate disruptions, optimize inventory, or align decisions across the network. Interviewees cited that master data problems exist, which result in processing errors and extended lead times. Prioritization is another recurring issue within the network. While there is a functioning logic for prioritization through tools such as iPOM and iOM, limitations remain. iPOM, used by Supply Network Specialists and Replenishment, prioritizes which POs to pursue based on the number of connected SOs. However, as several interviewees pointed out, this logic is enough to make decisive decisions yet lacks contextual depth. While a PO may have a higher number of connected SOs, this does not necessarily mean that its delay would result in greater value or impact. Similarly, iOM that is used by SACs, lacks prioritization support for deciding which orders justify escalation through raising tickets. This absence of contextual prioritization contributes to inefficiencies and misaligned decision-making across the network. In addition to prioritization challenges, interviewees highlighted limitations in alerting and order tracking capabilities. The network currently lacks proactive alert mechanisms that could flag disruptions or delays early, resulting in reactive handling of issues.

The flow of the physical parts is established and well-defined yet remains vulnerable to delays at multiple stages. These delays often result from poor synchronization between functions and the absence of real-time data and connectivity, ultimately affecting delivery performance and customer satisfaction. By mapping the current structure of the network alongside its processes and data streams, The Company is better positioned to ensure an accurate integration between physical and digital layers and is an essential prerequisite when addressing RQ2.

6.1.2 Research Question 2

RQ2: *How can a Digital Twin be used address current challenges problems at the spare parts network, and what is their perceived value relative to the effort?*

Digital Twin (DT) technology can address the spare parts network's challenges by transforming fragmented, reactive processes into proactive, data-driven operations. Moshood et al. (2021), emphasize that DTs can enable visibility and Ivanov et al. (2019) state that DTs include predictive analytics and scenario-based decision support with the help of simulation, optimization, and data analytics. These capabilities align closely with the SDAR framework introduced in section 2.4 that provides a structured approach to overcome the pain points identified in RQ1.

Surveillance is the foundation for overcoming the fragmented visibility and silos. The first step entails determining what entities, resources, or activities that should be monitored. It is an essential step to establish the unit of analysis and collect data. The most crucial thing to surveil according to interviews is the traceability of SOs, POs, and shipments. These can be surveilled by integrating ERP, WMS, and TMS data into a unified timeline, and DT to provide end-to-end visibility (Ivanov and Gusikhin, 2025). Here, the absence of integrated visibility can begin to be addressed. Detection starts to move operations from reactive to proactive by identifying deviations or emerging risks in the monitored data. A rule-based detection engine with impact-weighted thresholds triggers alerts for significant issues, e.g. extended lead times or customer delays, while predictive models can forecast supplier delays, congestion in the warehouse, etc. Initial thresholds are set by responsible employees. AI and machine learning tools can enhance detection by identifying patterns in historical and real-time data, and surface anomalies before they escalate. This step along with its capabilities can further enable proactive risk management and fill the gap in predictive tools and alerting mechanisms.

Action follows detection and addresses challenges regarding misaligned prioritization and lacking decision-support. DTs can provide descriptive, predictive, and prescriptive analytics (Ivanov, 2019) to recommend actions like split shipment or use dual sourcing. Prescriptive analytics can, furthermore, enable trade-off assessment (Schroeter et al., 2025). To take, for example, costs, lead time, and environmental impact into account before deciding on an action. A desired capability mentioned by interviewees. Additionally, DTs can enable scenario planning, "what-if" simulation analysis, enhanced collaboration among supply chain partners, and improve risk management.

While these advanced capabilities are fascinating, a critical disparity exists between the theoretical DT found in literature with the vision from The Company's perspective. The concept and view of a DT can differ based on the individual. For the spare parts network and the Command Centre, the vision of the DT, as the Digitalization Manager sees it, is data sources gathered in one place that where you can perform simulations. However, from the desired needs and visions from interviewees, the Command Centre is primarily a centralized data platform to unite multiple sources in real-time. This study reveals that simulation capabilities were deemed as low value by the interviewees compared to the immediate need for data connectivity and visibility.

Response is the last step and executes the chosen action and monitors the outcomes. Before choosing an action, the feasibility and expected impact are evaluated. After the response, the loop is closed and lays foundation for the surveillance frame in the future. Thus, the next cycle will be based on previous learnings (Brintrup et al., 2022).

Interviewees emphasized the desire for a playbook that provides guidelines for recurring issues. This can be enabled with the use of the cycles, which will strengthen resilience, and enable continuous improvement as the playbook and its guidelines will evolve with each cycle. Ultimately, DTs can support the Command Centre to become a proactive, adaptive control tower rather than a reactive coordinator. These capabilities can together aim to reduce delays, improve service levels, and enhance customer satisfaction.

Since the problems in the spare part networks are varied and diverse so are the solutions, a value-to-effort matrix was created to map out capabilities that would solve certain problems within the network. The analysis started by examining the effort that a solution would require and then the value the capability would bring, these were then mapped onto a matrix. The matrix was used to identify Quick-Wins, major projects and thankless tasks, which indicate which capabilities that The Company should begin focusing on. Among the Quick-Wins were end-to-end order visibility, dashboards, threshold-based detection and action recommendations.

The results of the value-to-effort analysis showed that some capabilities which are very closely associated with digital twin technology such as scenario simulation brought less value compared with other capabilities that are more seen as enablers of digital twins were the ones that brought the highest value such as the end-to-end visibility.

6.1.3 Research Question 3

RQ3: *How can a roadmap and conceptual framework be designed to support the implementation of a Digital Twin at the spare parts network?*

Based on the case study findings, there are several capabilities that are desired by interviewees, and capabilities that can be provided by utilizing Digital Twin (DT) technology. The capabilities that DT can contribute with and expected to bring value can be organized into three implementation phases to ensure scalability and progressive value creation. Table 24 presents the main capabilities and the three phases recommended to be implemented in the spare parts supply network, with the help of DT. Each phase builds on the previous one, aligning with the Value-To-Effort framework. The first phase includes the "Quick Wins" of functionalities for a Command Centre. The second phase includes "Medium" enhancements, with capabilities that can strengthen decision-support. The third phase includes long-term strategic capabilities. Capabilities that are expected to bring significant value but with the cost of noteworthy efforts. These phases are recommendations and outline what The Company should prioritize to bridge the gap between the challenges and potential of DTs to finally enhance decision-making, cross-functional collaboration, and provide visibility.

In phase 1, the foundational data backbone is established by integrating disparate ERP, WMS, and TMS systems to achieve end-to-end visibility and proactive alerting through role-based dashboards. Phase 2 introduces more advanced analytical capabilities, such as prioritization algorithms and scenario simulations, to enhance alignment between different functions in the Company. Phase 3 incorporates strategic, AI-driven functionalities like delay prediction and automated execution to realize the long-term transformative potential of the Digital Twin within the network. These are, based on their placement in the Value-To-Effort matrix, considered not as important short-term.

Ultimately, this phased approach ensures the network can address operational bottlenecks while building the necessary infrastructure for long-term strategic transformation. By starting on a restricted scale and focusing on the most relevant functions first, the implementation remains manageable and aligned with organizational readiness.

6.2 Contributions

Current research into Supply Chain Digital Twins has mostly been developing several conceptual frameworks for various purposes and as of 2025 a framework for how a digital twin can be designed was proposed by Ivanov (2025). However, research applying this technology specifically to spare parts networks remains limited. Furthermore, there is also a research gap for what industry and companies desire and expect from such systems. This thesis contributes by identifying how digital twin technology can be applied specifically to a spare parts network and how the technology matches the expectations from the company managing the network. Literature gaps identified by Gabellini et al., (2025) to be design frameworks that specify which data should be collected, which metrics should be predicted, and which decision-making processes ought to be supported. These gaps were partiality filled by the paper by Gabellini et al. but not in a spare parts context.

As highlighted in the introduction of this study, research regarding DT technology and supply chain visibility, especially in the spare parts network's context, is still in its early stages. Most literature today regarding DT technology is centered around production and manufacturing. This thesis therefore contributes to theory by applying and adapting existing frameworks such as SDAR and the four visibility pillars to a real-world case. It demonstrated how the models can be used to identify visibility gaps and guide the implementation of DTs in a global supply network. Additionally, a value-to-effort prioritization framework is introduced and is a novel way to evaluate and arrange DT capabilities. In turn, contributing to the theory on digital transformation. Furthermore, insights from interviews provide empirical foundation for the design and product of DSCTs, and how they can be deployed in complex supply chain environments.

The findings of this thesis also offer a practical contribution. It provides a structured and actionable approach to implementing DTs in a complex organizational setting. A three-phase implementation roadmap is proposed along with a detect & act system. These guides The Company to prioritize initiatives based on value, complexity, and feasibility. The study identifies that DTs can bring the most value to operational and customer-facing areas where visibility gaps and response delays are the most critical. The recommendations range from base improvements like data visualization to more advanced capabilities such as predictive analytics. These insights are not only relevant to the case-company, but they are also relevant to other organizations with similar characteristics. Organizations that conduct global operations have a high product variety, and fragmented systems. The study offers both immediate improvements and long-term strategic value.

6.3 Limitations & Future research

6.3.1 Limitations

The thesis, while providing valuable insights regarding DTs, was subjected to limitations that need to be acknowledged. An overall and natural constraint was the time frame of 20 weeks. A longer project duration could allow for a more in-depth collection of data and deeper analysis which in turn could broaden the scope. With more time, it would be possible to analyze emerging literature, conduct a multiple case study to compare different implementations, or even initiate an implementation of the solution. However, those efforts are time-consuming and deemed unrealistic due to the time limitations.

The selection and background of interviewees also introduced certain limitations. Most interviewees were based at the main DC, except for three employees. While these three provided valuable perspectives, an even broader representation would strengthen the credibility of the findings. Additionally, the interviewees' previous knowledge of DTs varied. Although many of them were aware of the Command Centre project, which was interpreted as a representation of DT principles, they are not synonymous. This affected the consistency and clarity of the responses. Furthermore, unfortunately did not every interviewee complete the follow-up survey we provided. The survey was aimed at prioritizing the challenges and capabilities discussed during the interviews as well as give the interviewees an opportunity to provide desired detection and alerts close to their hearts. The lack of answers may have skewed the number and types of challenges mentioned.

6.3.2 Future Academic Research

Although this study addresses key aspects of Digital Twin (DT) implementation within a spare parts supply network, several strategic, technical, and organizational dimensions remain unexplored. Future research should aim to deepen understanding in these areas and support the evolution of DT-enabled solutions. These directions can be considered in terms of feasibility and complexity, reflecting both technical effort and organizational readiness.

Beyond The Company's boundaries, future research should explore the expansion of DT capabilities to include suppliers and customers, enabling end-to-end visibility and collaborative risk management across the entire network. One particularly promising direction is the evolution of the CC into a chat-based interface powered by advanced language models, which could fundamentally change how decision-makers interact with complex systems.

6.3.3 Future Research for The Company

Research with high feasibility and lower complexity should focus on practical enhancements that can deliver quick results. One important area is the calibrations of thresholds for detection, ensuring that alerts are both timely and meaningful without causing unnecessary noise. Another promising step is the development of a comprehensive playbook that outlines appropriate actions for each detected issue, thereby standardizing responses and accelerating resolution. Creating an ontology for the supply chain to enable advanced simulation and scenario planning would also strengthen decision-making capabilities. Furthermore, exploring gamification mechanisms within the Command Centre (CC) could improve employee engagement and satisfaction, while investigating how DTs can support warehouse-level operations would extend the benefits of this technology to frontline activities.

More complex research directions involve significant technical development or organizational change. A key opportunity for future practical work is the integration of the supply chain DT with lower-level twins, such as those representing individual machines, to forecast breakdowns and align spare parts availability with maintenance needs. Another promising avenue specifically for The Company is the transformation of the CC into a conversational interface powered by Large Language Models and Retrieval-Augmented Generation, enabling intuitive and context-aware decision support. Incorporating external data sources, such as weather or geopolitical risk indicators, into the CC would allow proactive disruption management. Similarly, analyzing how autonomous AI agents can interact with the DT to detect anomalies, such as missing master data, represents an important step toward automation. Further research should also evaluate the effectiveness of machines learning models for predicting supplier delays and transport disruptions, particularly in low-volume, high-variety environments. Assessing the feasibility of developing the DT in-house using Microsoft Azure and Microsoft Fabric's Digital Twin Builder could provide insights into scalability and governance. In addition, defining a general framework for identifying which data is essential for building a Supply Chain Digital Twin and enabling accurate forecasting models would offer valuable guidance for future implementations. Finally, investigating collaboration between the spare parts network and supplier management to strengthen supplier capabilities and support dual sourcing strategies could enhance resilience and flexibility.

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8. APPENDIX

Appendix A1: English interview guide

Introduction

- May we record this meeting?
- Presentation of the interviews, scope and purpose of the master thesis
- **Topic**: Maximizing Value-to-Effort Using Digital Twins in a Rapidly Moving Spare Parts Supply Network
    - "The purpose of the thesis is to investigate how a digital twin can enable end-to-end visibility, improve decision-making in the spare part network, and serve as a cross-functional platform that fosters collaboration and breaks down silos."
- Brief introduction from interviewee, describe role and responsibilities at The Company

General

- What KPI's do you measure?
- What are the biggest operational challenges you face in the spare parts network today?
- How do these challenges affect the KPIs?
- Where do you see inefficiencies or redundancies in current workflows?

Command Centre & Visibility

- Do you know what the Command Centre is?
- How will a Command Centre assist your function and your work?
- Who would you think would benefit most from a Command Centre?
- What kind of real-time information would be most valuable to you?
- Are there any current visibility gaps that hinder your work?
- How do you currently detect delays or disruptions in the supply chain?
- What do you think would be the biggest cost or effort in implementing a Command Centre?

Cross Collaboration

- Are there any barriers to collaboration (e.g. systems, culture, structure)?
- How do you proceed when a problem occurs and how do you know who to contact?
- Do you think a shared platform like a Command Centre could support collaboration?

Connected to SDAR (If relevant to the interviewee)

- Is there any way to forecast disruptions in the supply chain? Can you plan for situations where a producer cannot deliver?
- How do you currently plan the supply network?
- Do you finance the development of production for your spare parts at your suppliers?
- How do you assess whether a supplier is reliable enough to invest in?
- Do you have any tools to detect if a supplier is likely to face financial problems?
- Do you have any tools to predict if a customer will face financial problems?

- What does a negotiation between customers or suppliers look like? What data do you rely on?
- Is there any tool to predict if a supplier will have an overflow of products?
- Are there tools to predict what price the customer or supplier will accept?
- What current techniques do you use to plan demand?
- How do you ensure that the quality of new suppliers is sufficient?

Closing Statement

- Do you have anything else to add?

Appendix A2: Swedish interview guide

Introduktion

- Får vi spela in mötet?
- Presentation av intervjuerna, omfattning och syfte med examensarbetet
- Ämne: **Maximiera värdet i förhållande till instats genom Digital Twins i ett reservdelsnätverk**
    - Syfte: ”*Syftet med examensarbetet är att undersöka hur en digital tvilling kan möjliggöra end-to-end visibilitet, förbättra beslutsfattande i ett reservdelsnätverk och fungera som en tvärfunktionell plattform som främjar samarbete och bryter ner silos*”
- Introduktion från intervjupersonen: beskriv roll och ansvar i företaget

Allmänt

- Vilka KPI:er mäter ni?
- Vilka är de största operativa utmaningarna ni möter i reservdelsnätverket idag?
- Hur påverkar dessa utmaningar KPI:erna?
- Var ser du ineffektivitet eller dubbelarbete i nuvarande arbetsflöden?

Command Centre & Visibilitet

- Vet du vad Command Centre projektet är?
- Hur skulle ett Command Centre kunna stötta din funktion och ditt arbete?
- Vem tror du skulle ha störst nytta av ett Command Centre?
- Vilken typ av realtidsinformation skulle vara mest värdefull för dig?
- Finns det några nuvarande synlighetsluckor som hindrar ditt arbete?
- Hur upptäcker du idag förseningar eller störningar i supply chainen?
- Vad tror du skulle vara den största kostnaden eller instatsen för att implementera ett Command Centre?

Cross Collaboration

- Finns det några hinder för samarbete (t.ex. system, kultur, struktur)
- Hur går du tillväga när ett problem och hur vet du vem du ska kontakta?

- Tror du att en gemensam plattform som ett Command Centre skulle kunna stödja samarbetet?

Kopplat till SDAR

- Finns det något sätt att förutse störningar i supply chainen? Kan ni planera för situationer där en producent inte kan leverera?
- Hur planerar ni idag leveransnätverket?
- Finansierar ni utvecklingen av produktion för era reservdelar hos leverantörer?
- Hur bedömer ni om en leverantör är tillräckligt pålitlig för att investera i?
- Har ni några verktyg för att upptäcka om en leverantör sannolikt kommer att få ekonomiska problem?
- Har ni några verktyg för att förutse om en kund kommer att få ekonomiska problem?
- Hur ser en förhandling mellan kunder eller leverantörer ut? Vilken data baserar ni er på?
- Finns det något verktyg för att förutse om en leverantör kommer att ha ett överskott av produkter?
- Finns det verktyg för att förutse vilket pris kunden eller leverantören kommer att acceptera?
- Vilka nuvarande tekniker använder ni för att planera efterfrågan?
- Hur säkerställer ni att kvaliteten hos nya leverantörer är tillräcklig?

Avslutande fråga

- Har du något mer att tillägga?

Appendix B: Survey

1. What is your role in the spare parts supply network? *
2. What capabilities would you most appreciate in the Command Centre? Please rank from the most valuable to least valuable (Not Important, Slightly Important, Moderately Important, Very Important, Essential) *
    a. Automatic detections of deviations
    b. Suggestions for solutions to problems
    c. Network wide prioritization method
    d. AI Forecasts of anticipated problems
    e. Real-time visibility
    f. Self-learning system based on historical solutions
    g. Scenario Simulation
    h. Simple, role-adapted dashboards
    i. Feedback regarding impacts based on decisions (Cost vs. CO_2 vs. Lead Time, etc.)

3. Feel free to add comments here regarding capabilities mentioned above (e.g., specify why real-time visibility would be beneficial, or if you ranked two capabilities as "Essential" but want to specify that one is even more important than the other)
4. What would make the Command Centre most valuable to you? (e.g., what information do you want displayed in a dashboard?) *
5. How beneficial do you expect the Command Centre to be in your work? (1 = Not beneficial at all, 10 = Very beneficial, could see yourself using it every day) *
6. Rank the importance of data from each source
    a. WMS (SAP WMS)
    b. ERP (SAP ECC)
    c. TMS (AEB)
    d. External (Weather, Geopolitics, etc.)
7. Please give suggestions for problems that you would like the Command Centre to detect and (if possible) proposed action to the problem. Example:
    a. **Detect:** High priority order **Action:** Reserve location for order
    b. **Detect:** Significant delay in shipment **Action:** Notify relevant team

Appendix C: Extended table of interviewees

Table 25: The extended table of interviewees with the roles, purpose and additional information

Interviewee	Role	Purpose	Date(s)	Duration	Method
A	**Digital Twin Engineer**	Gather detailed insights into digital twin technology, its implementation process, data requirements, and integration with existing systems	2025-07-29	60 min	Digital
B	**Digitalization Manager**	To obtain an overall understanding of the spare parts network operations, key challenges, and how Digital Twin technology aligns with the Command Centre initiative	2025-08-06	60 min	On-site
C	**World Class Manufacturing Manager**	Gain a deeper understanding of warehouse operations, performance metrics, and improvement initiatives	2025-08-06	60 min	On-site
D	**Integrated Network Manager Americas**	To capture perspectives from Distribution Center (DC) employees, including operational challenges and perspective of current processes	2025-08-06	60 min	Digital

E	**SR Business System Analyst**	Gain insights into operational challenges, system dependencies, and visibility issues within support processes.	2025-08-12	60 min	On-site
F	**Supply Network Specialist**	Understand the role, connections with supplier management, prioritization strategies, and expectations for the Command Centre	2025-08-13	60 min	On-site
G	**Manager Global Operational Support & OT Security**	To clarify the role of Global Operational Support, its relationship with other functions, and security considerations in operational technology.	2025-08-14	60 min	On-site
H	**Manager Planning & Inventory Optimization**	Assess expectations for the Command Centre and its integration with the new planning system, including capabilities and limitations	2025-08-14	60 min	On-site
I	**Global Planning & Data Expert (Group interview)**	To gather information on the new planning system's functionalities, its' overlaps with the Command Centre, and capabilities	2025-08-18	75 min	On-site
J	**Director of Optimisation**	To gather overview and expectations of the Command Centre project. Gain insights regarding a potential detect and action system	2025-08-21 2025-09-04	45 min 60 min	On-site
K	**Replenishment Manager**	Understand operational workflows, replenishment challenges, and the connections between supplier management, supply network specialists, and planning process	2025-08-21	60 min	On-site
L	**Integrated Network Manager APAC**	Capture the perspectives from APAC DC employees, focusing on operational challenges and improvement opportunities	2025-08-25	60 min	Digital
M	**Supply Network Specialist**	Explore expectations for the Command Centre, supplier management practices, KPI differences, overlaps with the new planning system even further	2025-08-27	60 min	On-site
N	**Customer Service Excellence Manager**	To understand the customer perspective, customer service challenges, focusing on how the Command Centre can enhance customer experience	2025-08-28	60 min	On-site

O	**Distribution Center Manager Brazil**	To capture insights into the DC operations in Brazil and understand their challenges and perception	2025-09-04	60 min	Digital
P	**Supply Optimisation Manager**	Perspective from supplier management on the spare parts network, leveraging the interviewee's prior experience in supplier management	2025-09-05	60 min	On-site
Q	**Director of Planning & Quality**	Explore strategic requirements for the Command Centre in supporting planning and quality processes within the spare parts supply network	2025-09-08	60 min	On-site
R	**Sales Administration Manager**	To capture the sales perspective, operational challenges, and potential benefits of a Command Centre.	2025-09-08	60 min	On-site
S	**Sales Administration Manager**	To gain further perspectives from a sales administration and further explore how a Command Centre could support its operations	2025-09-22	60 min	On-site
T	**Logistics Solutions Manager**	Gather insights on the Transport Management System (TMS) and how it can supply the Command Centre with data. How data in the TMS is collected, stored and used.	2025-09-26	60 min	On-site

Appendix D: Topics Discussed & Challenges with interviewees

Table 26: Summary of discussed topics and challenges with each interviewee

Interviewee	Role	Topics discussed	Challenges
A	Digital Twin Engineer	Information regarding digital twin technology, implementation, relevant data, benefits of Digital Twins etc.	- Cybersecurity - Biggest early barriers **are live data collection and messy historical data**; success requires pipelines, protocols/APIs, and quality checks (missing/nulls, normalization) o “real time communication the main challenge” - **Security & access control** – must incorporate basic security from day one (certificates, signatures/keys) to protect

			sensitive data and control streaming connections
B	Digitalization Manager	Scope of project, Command Centre, Digital Twins, Spare Parts Network	Data quality and completeness (ensuring reliable and timely data across systems). User adoption: making the system intuitive and valuable enough for widespread use. Value creation: Measuring and proving the added value of the system to justify its case. System accuracy: Operational processes require near-perfect reliability
C	World Class Manufacturing Manager	WCM (lean-based methodology), operational work process, cross-functional collaboration, pillar structure, inventory planning	- Outbound is identified as the constraint. - Sense that inbound ordering sometimes exceeds needs, creating dead stock and storage pressure - Siloed thinking - Inefficiencies in inventory planning
D	Integrated Network Manager Americas	Team structure, planning process, data & KPIs (Global availability, transport performance, order confirmation),	- Local transport companies, manual data collection, lack of system integration, tariffs - Silos persist often caused by carrier data dependencies and uneven information updates across countries. Heavy reliance on the local carriers with limited digital capabilities - Limited visibility (especially for delays in transportation, supplier delivery, and warehouse operations) - Disconnected systems (SAP,TMS, etc.) hinder end-to-end tracking, lacking product classification and origin data affect customs clearance times, increasing delays - Limited capability to simulate constraints (e.g. air capacity) and quantify cost/lead-time impacts quickly for decisions - **Forecasting** issues where planning is history-heavy and manual; underuses installed base, running hours, and maintenance data for proactive forecasting

			- Mismatch between planned deployments and carrier daily allocations creates overflows and downstream delays; needs tighter linkage - Tariffs and stricter classification increased customs release times and forced network re-routing, affecting service and cost
E	SR Business System Analyst	Operational support across global logistics systems (SAP, TMS, etc), Hybris, KPIs, GOS acts as a bridge between global users and system teams	- Orders placed outside Hybris lack integration with tracking tools, customers often rely on support teams to locate orders and shipments, not all disruptions are reflected in metrics
F	Supply Network Specialist	Role & function, new planning system, visibility challenges and expectations from command centre, operative challenges, KPIs, motivation and understanding of influence employees have (similar to gamification)	- Data quality/accuracy, lead time variability (some suppliers exceeding 200 days) - Limited supplier contact (especially with smaller vendors) - System limitations (current tools lack simulation capabilities and real-time responsiveness) - Crisis readiness (difficulty predicting and handling supplier crisis). Cyclical macro swings plus supplier-specific shocks create extreme lead-time spikes and shortages - Adding new suppliers is hampered by quality/validation at scale; cannot compromise quality even under pressure
G	Manager Global Operational Support & OT Security	Operational support across systems and global sites, cybersecurity risks and OT/IT boundary, KPI relevance and overlap, potential of the Command Centre	- **Visibility gaps**, difficulty knowing what information is missing (“hard to know what you don’t see”), lack of overview of ongoing projects - **Cybersecurity risks,** risks of misinformation (“better to have no data than wrong data”)

			- KPI misalignment, KPIs should be actionable; current ones sometimes measure outcomes that teams cannot influence directly - **Zero-sum workload reality**, The team balances competing urgencies; helping one request faster often delays another - Support often relies on personal experience and relationships (people reach out directly to an employee instead of shared inbox) rather than structured systems. **“Street-smart” networks**, who to contact relies on **tenure and personal networks**; roles aren’t systematically mapped
H	Manager Planning & Inventory Optimization	New planning system, scenarios, **gamification (motivation through impact tracking**, planning logic (historical sales, predictive maintenance, new machine rollouts), Visibility, alerts, prioritization based on **customer impact.** Planning system & functionality (current and future), KPIs	- **Data integration gaps**, no automatic link between maintenance events and planning, manual input required for new machines and predictive maintenance data. - **Alert limitations**, current tools lack proactive alerts, no system-level notifications for trends like increasing transport times or supplier delays. - **Organizational ambiguity**, unclear who should act on specific issues, planning team often takes on responsibilities beyond their scope. - Today the demand forecasting is mostly historical data. The aspiration is to inject maintenance (“service events”) data, especially for contracted customers, to predict needs.
I	Global Planning & Data Expert (Group interview)	New planning system “Maestro”, provided by Kinnaxis (and Deloitte). Shared data foundation between Maestro for planning and Command Centre for operational visibility. User	**Systems are outdated** (especially lacking real-time simulation), licensing and access limitations (connected to new planning system), **gaps in end-to-end tracking** (e.g. limited connection to logistic providers TMS), manual excel-analysis required during more extensive network changes),

		Stories, integration challenges, and data quality issues, **pegging**	
J	Director of Optimisation	DSCS, spare parts network functions and silos, end-to-end supply chain flow from sales order to final delivery to customer, fragmentation between systems and organizational silos, command centre as a unifying and decision-driven layer, AI agents for detection and prioritization, benchmarking against DHL's operational excellence.	**System fragmentation** where multiple systems (ECC, EWM, etc.) operate independently with no clear ownership of handovers. **Lack of visibility** across segments leads to inefficiencies and missed shipments. **Multiple systems/modules don't fully interoperate**; some "live their own life," causing stuck orders and invisible backlogs **technical issues (System landscape)** **Master Data issues** - missing or incorrect article and customer master data (e.g. HS codes, CoO) cause compliance issues and shipment delays. **Manual detection & escalation** – detection of issues is reactive and often too late. There is no structured process for prioritizing or resolving disruptions. **Capacity planning gaps** – no real-time monitoring of picking capacity vs. Order volume --> risk of underperformance due to lack of proactive stagging or rerouting **Silo gaps** where teams and systems operate in silos with unclear ownership of the "in-between" handoffs, creating friction and blame loops.
K	Replenishment Manager	Operational work process, transparency across functions related to Command centre (bridge gap between customer expectations and supplier realities), market input reliability (SAC tickets) and how much can be raised, prioritization, KPIs,	Managing high volumes of PO lines, ensuring reliable supplier, overload from market-driven urgency requests, capacity issues (we order a lot, but supplier does not have the full capacity to fulfill the orders), demand goes up and causes stock-out at supplier resulting in long lead-times to restock,
L	Integrated Network Manager APAC	Operational and strategic aspects of SCM within the network (planning, replenishment, and quality control across APAC, India, and Dubai). Potential of DT and CC	- **Planning System Errors & Manual Overrides**. Intermittent system errors (e.g. safety stock updates, long supplier lead times) trigger wrong PR/PO quantities; teams must detect anomalies and execute manual corrections until fixes land - **Plan orders vs priority orders**: rare, very large same-day priority drops

			(200-300 lines) create short-term capacity strain despite generally "soft" demand - **Contracts/TPMS** orders exist but automated stock protection/allocations are immature, manual, and not scalable across sites
M	Supply Network Specialist	DT & CC use cases: simulation of supplier parameters (MOQ, lead time, price) and their impact on stock value and cost performance. CC functionality (as a decision support and execution tool, not just planning system. Should visualize data relationships, suggest actions, and enable proactive communication).	- **Data fragmentation** where data is spread across excel sheets making it difficult to analyze. - **Supplier constraints**: long lead times and high MOQ negotiated for lower price often leads to high capital binding and inflexibility. - **Limited visibility**, lack of real-time visibility into how supplier decisions affect downstream operations and customer satisfaction. - **Manual processes,** many double checks and validations are manual, including verifying purchase orders and matching forecasts. - **Non-optimal MOQ relative to EOQ** increases working capital despite lower unit prices; need dynamic what-ifs
N	Customer Service Excellence Manager	Customer Service Excellence, Customer expectations (increasing demand for real-time updates, transparency, and self-service capabilities), CX, the tool landscape (ECC, Salesforce, e-business portal, RPA, etc.) with efforts to unify and simplify access, change management, Command Centre Vision – a unified, intuitive platform for end-to-end visibility and proactive issue detection	- **Lead time & availability** - **Order follow-up & tracking**, obsolete parts confusion, tool fragmentation, manual workload, limited e-business adoption
O	Distribution Center	Traceability & visibility, customer communication, prioritization logic, supplier	**Lack of pre-shipment and in-DC visibility** since they have no WMS.

	Manager Brazil	interface, workarounds (cannibalization and local sourcing to keep customers running)	**Reactive communication with customers; no proactive alerts.** **Prioritization gaps** (no downstream impact when reallocating parts) Manual processes and fragmented tools Staff need **Impact Alerts** when forcing deliveries that affect other orders. ("an easy way to understand orders that will be impacted if I use that part…"
P	Supply Optimization Manager	OEM vs (X) parts, Performance monitoring, Relationship dynamics, Obsolescence & Disruptions, Sub-tier dependency blind spots, cost & criticality weighting, dual/multi-sourcing	High dependency on OEM suppliers, **Manual risk detection**, **Escalation inefficiency** (penalties rarely used), **System fragmentation** (supplier collaboration tools hard to implement), **Limited dual sourcing,**
Q	Director of Planning & Quality	Visions for the Command Centre, Customer Communication, roles & decision ownership, Sustainability & cost tradeoffs, transformation goals, Actionable Decision support	- Reactive processes - Ownership ambiguity - Limited scenario planning - Sustainability blind spots - Unclear who should act on alerts and recommendations; may require a new or redefined role and/or routing by process area
R	Sales Administration Manager	SAC responsibilities and workload, Visibility issues in SAP, customer communication and order tracking	**Fragmented systems**, **lack of End-to-End visibility,** long learning curve for new employees, **reactive communication with customers**
S	Sales Administration Manager (Sara)	Market behavior, order & flow visibility, customs and documentation, cases and prioritization	**Lack of End-to-End visibility** for SAC teams and customers. **Customs** delays due to fast-changing rules. High workload from repetitive status queries. Resistance to standardization in some markets.
T	Logistics Solutions Managers (2 Interviewees)	TMS System and its capabilities, its Data Architecture, Fault Codes. TMS API, TMS Analytics, how the TMS system compares to the Command Centre	The implementation of the Command Centre might implicate a large organization shift in order to make use of **the end-to-end visibility**, new end-to-end team might be necessary

Appendix E: Full table of interviewees mentioned desired capabilities and key takeaways

Table 27: Summary of answers regarding desired capabilities & the author's key takeaways

Interviewee	Desired Capabilities	Key takeaways
B	• Problem-graph & impact propagation across functions (who is affected, where, when) • End-to-end detection & alerting in hardest-visibility zones • Operational workbooks for proactive roles • SDAR-aligned data fabric (Sources–Decisions–Actions–Results) & governance • Comparative impact logic (e.g., 1-month vs 1-week delay → which supplier/customer) • Value–to–Effort mapper (capability-by-function)	The theoretical background should guide the right path – which capabilities to focus on and which areas to **prioritize**. Where is visibility difficult atm? Where is it valuable to enable detection? Describe the different problems across functions – **and connect them!** The key is the **relationship** between data – it is not the "live" aspect that defines it as a **digital twin.** The model should identify problems and show how they affect everything else. For example: a 1-month delay vs a 1-week delay; which supplier should you contact? What customer to prioritize? For **value-to-effort:** treat the DT as **Value Chain Mapping** – assess value-to effort in each function.
C	• Self-optimizing flows (automation > dashboards) • Bottleneck detection & optimizer (dynamic re-sequencing) • Time-to-Stock tracker & reducer (closed-loop)	Maxim prefers systems that self-optimize without requiring manual monitoring. The system should just work. Automation over visibility. Two key priorities: **Bottleneck optimization** and **Time-to-Stock reduction.**
D	• Supplier + transport integration (esp. local providers in Americas), • End-to-End delay tracking with proactive notifications • Regional supplier performance views	Command Centre seen as a critical solution to unify systems and improve responsiveness, visibility essential to reduce delays and improve customer communication, supplier and transport integration is a major gap, especially in Americas where countries rely on local providers. Limited visibility into supplier performance and transport delays across regions
E	• Customer **self-service order tracker** (deflects "where is it?") • **Reliability SLOs** & data-quality monitors (avoid "DT gone wrong") • **Value–to–Effort** gating; **pilot-first**	Not expected to be used directly by Operations Support but may reduce workload by enabling customer self-service tracking in command centre, indirectly improving efficiency. Regarding DTs: reliability and integration quality are critical. **Poorly implemented DTs can increase manual workload rather than reduce it**. Therefore, it is important to consider the areas where it would help the most. To implement a DT in an area where function works well, without gaps, the benefits would be limited compared to the effort.
F	• **Criticality scoring** (article/customer) & **impact preview** • **Action recommendations + owner routing**	Angelica would like the command centre to easy identify critical articles and their impact, to suggest solutions and responsible contacts during distruptions, bridge gap between planning team and teams who work operatively, create a more proactive and data driven work environment, and centralize visibility and decision-making. **Prioritization** based on **customer impact** is key.

	• **Ops–Planning bridge** (shared board) •**Customer-impact-based prioritization** & **centralized visibility** • **Early surfacing** of problems with **concrete next actions**	
G	• **Role-based ticketing & RACI** (not person-based) • **Cross-silo visibility** & network map (roles/flows/projects) • **Workload & impact tracker** for GOS • **Secure-by-design rollout** with early Support/Security • **Early surfacing of issues** for faster resolution	Resistance to change may rise – potential pushback against structured systems like a command centre due to preference for informal, fast solutions. Command centre could improve visibility into roles and responsibility - preferably direct role-based tickets (not person-based). He emphasized the need for robust, reliable implementation and early involvement of support and security teams. He advocates for breaking silos and fostering shared understanding across teams --> mutual awareness of how actions affect others in the network. GOS often resolves issues without escalation. The team has high system access and autonomy but lacks formal tools for tracking workload and impact. He would appreciate a visual oversight of the supply network and active projects.
H	• **Real-time risk engine** with **alerts + recommended actions** • **Action-impact loop** & **gamified scorecards** • **KPI cockpit**: Availability, Inventory Turnover, Lead-time, Cost Savings, Delivery Precision • **Progressive automation** (ML-assisted)	His vision for the command centre is "the brain on top of the brain" - complementing the planning system with real-time risk analysis and decision support. CC should provide alerts, suggest actions, and potentially automate decisions in the future based on historical patterns and machine learning. He emphasized the importance of showing the **impact of actions** to motivate staff, **gamification**. Suggests tracking savings, improved service levels, and delivery precision as feedback mechanisms. He believes this could foster a stronger understanding of individual contributions. The KPIs are: - Availability (was the part there when needed?) - Inventory turnover rate - Lead time reduction Cost savings and delivery precision
I	• **Pegging visualization**: **who gets what, when, how** (shortage rules) • **Allocation transparency** (show **who receives the ten**) • **Unified comms & visibility** across roles/regions • **Lead-time spike / demand-surge detectors** • **Linked documentation** across objects	Command Centre seen as a bridge and aims to unify communication and visibility across roles and regions. Help detect issues like long lead-times or demand spike. Linking digital documents with each other is a wishful feature of the CC. **Pegging logic** is **central**: allocates specific inventory quantities to defined needs and answers the question: "Who gets what, when, and how?". Pegging is based on clear rules and **priorities**, which is crucial in shortage situations and forms the foundation for Command Centre Visualization. **Scenario simulation is crucial** for the planning system (Not CC).
J	• **Central action-orchestrator** (detect → prioritize → direct) with authority + reminders • **AI agents** for data gaps, parsing inbound orders/emails,	Command Centre should act as a **central brain** that detects, prioritizes, and directs actions across the supply chain. Needs to be process-driven, not person-dependent. **AI agents** can scan for missing master data, package issues, and assign them to responsible teams. The command centre should support early detection of disruptions and recommend actions based on predefined

	auto-package fixes, task dispatch with SLAs • **Capacity balance** (pick workload vs staffing) w/ predictive signals • **External risk sensing** (weather, geopolitics, capacity) + short daily brief, actions via playbooks • **Customer portal + proactive comms** • **Incident KB & playbooks** (gen-search) • **Credit-limit** shipment gate, early warnings • **Unified KPIs**	**playbooks**. It will be essential to understand how a delay or disruption can affect downstream sales orders and customer deliveries. CC should **track the impact of actions** to motivate teams. **Visibility into outcomes helps reinforce the value of proactive work**. Potentially benchmark against DHL, where they use weather, geopolitical, and capacity data to reallocate and reroute in minutes. It could be beneficial to learn from their structure, parameter thresholds, and decision logic. **Unified KPIs** – to align priorities.
K	• **Single-voice** supplier comms (auto-CC purchasing specialist) • **Customer–supplier bridge** to reduce manual loops • **Demand-capture / horizon-gap detector** (LT > planning horizon, plan glitches) • **Disruption sensing + early warnings** with **thresholding** (avoid noise) • **Contract-weighted** prioritization & **savings attribution** • **Human-in-the-loop** controls	Prioritization and thresholds (what to prioritize, when to take actions, and the impacts on KPIs), transparency. Command Centre must balance automation with human oversight. Not data from markets – it's impression from humans at markets on what is important. Tracking "savings" made from completing specific order lines would be nice. Customers with contracts hold more weight than normal ones. Command centre being a unified voice (e.g. to remind). She wants CC to detect "Captures on demand", and when lead-time is longer than planning horizon and therefore does not get triggered.
L	• **End-to-end shipment visibility** with accurate ETA (unify fragmented carriers) • **Near real-time refresh** (pragmatic **hourly SLO**) + **data-sync health** monitors • **Stock-risk detection** & **decision previews** (pros/cons) to avoid adverse outcomes • **Customizable dashboards** (balance too much vs too little info) • **Detect-and-action loop** (surface → suggest next step)	Importance of SCV, responsiveness, customer-centricity (revolves around lead time reduction and inventory efficiency), System reliability and data accuracy (synchronization) crucial, wishes for customization and flexibility in Command Centre
M	• **Dynamic parameter sandbox** to target materials for **LT/MOQ negotiation**	**Command Centre should enable dynamic simulation** of supplier parameters to support smarter decisions and reduce inefficiencies. **Visualizing total cost impact** of SuM decisions (e.g. EOQ vs MOQ) is crucial for aligning supply management with operational goals. **Proactive risk mitigation and prioritization** based on real-time data

	• **Interactive chat** to query company data alongside dashboards • **Integrations** with supplier IS & customer portals for shared status (**redact sensitive supplier data, e.g., price**) • **Total-cost (EOQ/MOQ)** views surfaced from Planning into CC	and alerts are essential to avoid stock-outs and delays. **Cross-functional transparency** is key – Command Centre should bridge silos and support collaboration across planning, supply, and customer service. **Benchmarking lead times** (14 days) and identifying critical materials can help focus improvement efforts where they matter most.
N	• **Unified SAC dashboard** (fast lookup via **Order Confirmation** #) • **Global risk push-notifications** to customers/markets • **Customer self-service portal** for tracking • **Salesforce–ECC–CC integration** • **Perfect-order logic** at **order level** (maintenance readiness) • **Predictive insights** for proactive comms • **UI simplicity guardrails** (role presets)	**The potential of the Command Centre** – unifying visibility, automating notifications, supporting SAC teams with real-time information. **Customer-centricity**: tools and efforts aim to improve satisfaction through transparency, responsiveness, and proactive communication. **Dashboard simplicity** – the SAC teams need clear, easy, fast-access dashboards with minimal layers to respond effectively to customer inquiries. Not having **too much information**. The most common number to receive from customers is the Order Confirmation (around 80%) **Global Risk Notification** – delay alerts should be sent proactively and globally. **Integration Opportunities** – Command Centre could replace or integrate existing tools to streamline workflows and improve transparency **Perfect Order Focus** – the different views of availability? How availability can be tracked on successful order lines, but customers measure it at order level, especially for planned maintenance events. E.g. maintenance but not all crucial parts arrive leads to them not being able to proceed with the maintenance **Customers are more satisfied** if they can fix it themselves through the e-business. (?) However, this depends on the region
O	• **Single lifecycle dashboard** (pre-shipment → in-DC → transport) • **Proactive delay/risk notifications** • **Impact-aware prioritization** (downstream consequence preview) • **Supplier escalation tracking** + **clear expedite lanes/costs** • **Integrations** to reduce Excel/BI/manual work	Command Centre **should** provide a single dashboard for visibility across order lifecycle. **Proactive notifications** for delays and risks are critical. **Impact-aware prioritization**: Show consequences of reallocating parts. **Supplier escalation tracking** and clear expedite options. **Integration of multiple systems into one interface to reduce manual work**
P	• **Risk sensing & early-warning worklist** (pre-delay) • **Criticality-weighted KPIs** (e.g., CWOTD)	**CC should** include risk sensing and proactive alerts. Criticality-weighted KPIs **“Guardrails” for MOQ and sourcing rules**: simple guidelines preferred over complex analysis

	• **Sourcing guardrails** (MOQ & rules with simple overrides) ‘ • **Supplier/sub-tier** signals as exceptions	
Q	• **Data unification & exception engine** (only meaningful alerts) • **Decision support** with recommended options (**LT vs Cost vs CO_2**) • **Customer transparency**: real-time tracking + **evidence-based updates** • **Role/RACI clarity** (who acts) • **Dynamic rerouting / multipath** with **time/cost/CO_2** • **Sustainability panel** (CO_2 in every trade-off) • **Data-health tiles** (feed freshness & blind spots)	Command Centre must unify data streams and surface only meaningful exceptions. **Decisions support should include recommendations and scenario simulations** (e.g., LT vs. cost. Vs. CO2) **Customer-facing transparency**: Real-time tracking and proactive updates **Clear role definition** – Who will be responsible? **Dynamic rerouting and multipath fulfillment –** present alternative routes with KPIs (cost, time, CO2) **Sustainability integration**: show CO2 in tradeoff decisions **Visualize** feed freshness and blind spots
R	• **Real-time SAC dashboards** to cut manual checks • **Unified navigation** across flows/transactions • **Centralized visibility** to reduce workload	SAC teams need **real-time dashboards** to reduce manual checks. Simplified navigation and unified view would improve efficiency. Command Centre could centralize visibility and reduce workload
S	• **Single, accurate flow view** (incl. **customs**) + **auto-notifications** • **Customer self-service tracker** (deflect ~**90%** “where is it?”) • **Proactive customs & delay alerts** • **Supplier redaction** for customer views (show timing/locations, not identities) • **AI agents** for automation & language support	Command Centre **should** centralize visibility and automate notifications. **Customer self-service portal** for order tracking could deflect 90% of cases. **Proactive alerts** for customs and delays to reduce firefighting **AI and automation** could reduce manual work and language dependency.
T		

Appendix F: Value-To-Effort

Table 28: Value-to-Effort table with corresponding pain points, capabilities and solutions

#	Pain Points	Desired Capability	Solution (actionable & grounded in Theory)	Value/Effort
1	Fragmented System Visibility	End-to-End visibility, SO-PO-shipment traceability, Track & Trace, "One universal Truth"	Implement a unified "Order Timeline" by integrating ERP, TMS, WMS connection into a single dashboard	Very High/ Low
2	Customer Transparency	Customer visibility (self-service portal). Customer transparency	Launch role-adapted dashboard plus a customer self-service via e-commerce/ SalesForce integration	High/ Low
3	Reactive issue communication	Automatic Detection of issues	Establish a rule-based detection engine with impact-weight thresholds (SDAR). Once threshold has been reached, it is detected, and action is suggested	Very High/ Low
4	Limited predictive capabilities	Issue forecasting & Congestion predictions	Develop a ML model for delay-risk (supplier/transit/picking) and AI-driven models to generate forecasts, e.g. punctuality, demand fluctuations, etc.	High/High
5	Reactive delay handling	Assisted delay handling & Decision-support (Action recommendation)	Provide prescriptive decision-support with recommended actions and quantified trade-offs, link actions to SDAR-aligned playbooks for consistent execution. Assist what actions to take when a delay has occurred. Include a dual-sourcing fallback	High/Mediu m
6	Absence of impact-based allocation logic	Impact aware allocation & Trade-offs (network-wide pegging)	Deploy a prioritization/pegging engine with weighted rules (contract criticality, lateness, customer impact) and consequence previews (time/cost/CO_2)	High/Mediu m
7	Incomplete Documentation/ master-data issues	Detection and alerts of issues that can cause delays	Run as an Agent responsible for checking master data quality (HS code/CoO/doc completeness). Add "data-health-tiles" that display the completed percentage and reveal blind spots	Medium/ High
8	Reactive external risk management gap	External risk detection	Incorporate exogenous risk feeds (weather, strikes, geopolitics), suggest actions based on playbook with proactive handling & customer	Medium/ Very High
9	Lack of Scenario simulation	Scenario Simulation ("What-ifs")	Enable a what-if simulation sandbox for different parameters, routing, inventory and capacity	Medium/ High

10	Manual decision-making dependency	Fully autonomous decision-making	Evolve decision-making to autonomous using AI agents that can make informed and reliable decisions.	Very High/ Very High

Appendix G: Survey

Master Thesis Survey

Thank you for participating in our interviews, they have been extremely helpful! We have gathered challenges and identified possible capabilities in the Command Centre that could help solve these challenges. We would immensely appreciate if you could fill out this survey - it should only take a few minutes to complete :) Best regards, André & Oskar

* Required

* This form will record your name, please fill your name.

1. What is your role in SSN? *

2. What capabilities would you most appreciate in the Command Centre? Please rank from most valuable to least valuable *

	Not Important	Slightly Important	Moderately Important	Very Important	Essential
Automatic detections of deviations	○	○	○	○	○
Suggestions of solutions to problems	○	○	○	○	○
Network wide prioritization method	○	○	○	○	○
AI Forecasts of anticipated problems	○	○	○	○	○
Real-time visibility	○	○	○	○	○
Self-learning system based on historical solutions	○	○	○	○	○
Scenario Simulation	○	○	○	○	○
Simple, role-adapted dashboards	○	○	○	○	○
Feedback regarding impacts based on decisions (Cost vs. CO2 vs. Lead time, etc.)	○	○	○	○	○

3. Feel free to add comments here regarding capabilities mentioned above. (E.g., specify why real-time visibility would be beneficial, or if you ranked two capabilities as "Essential" but want to specify that one is even more important than the other)

4. What would make the Command Centre most valuable to you? (E.g., what information do you want displayed in a dashboard?) *

5. How beneficial do you expect the Command Centre to be in your work? (1 = Not beneficial at all, 10 = Very beneficial, could see yourself using it every day) *

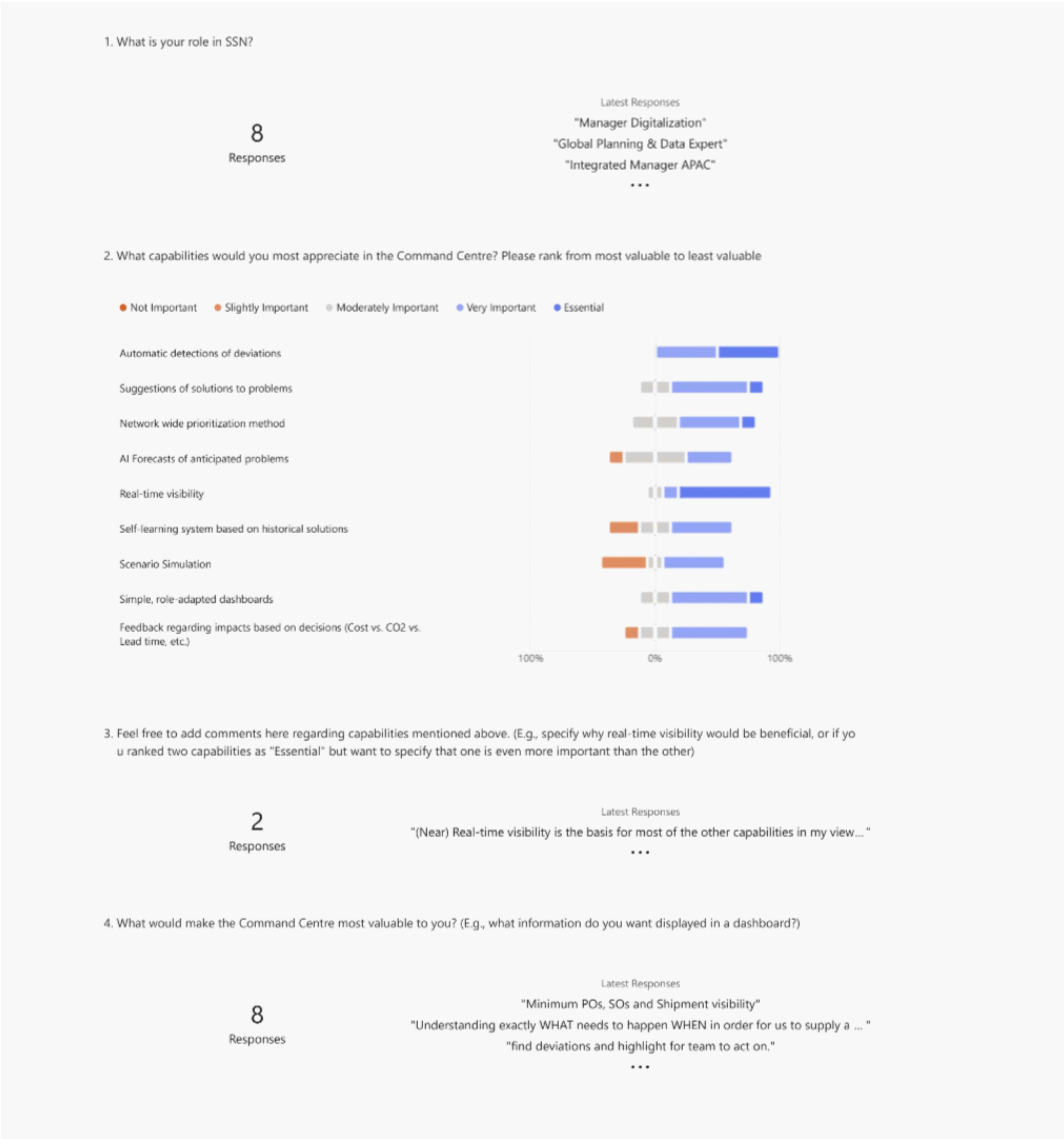
1	2	3	4	5	6	7	8	9	10

6. Rank the importance of data from each source *

- WMS (SAP WMS)
- ERP (SAP ECC)
- TMS (AEB)
- External (Weather, Geopolitics, etc.)

7. Please give suggestions to problems that you would like the Command Centre to detect and (if possible) a proposed action to the problem. Example:
Detect: High priority order **Action**: Reserve location for order
Detect: Significant delay in shipment **Action**: Notify relevant team

Appendix H: Survey Result



5. How beneficial do you expect the Command Centre to be in your work? (1 = Not beneficial at all, 10 = Very beneficial, could see yourself using it every day)

6. Rank the importance of data from each source

1 ERP (SAP ECC)
2 WMS (SAP WMS)
3 TMS (AEB)
4 External (Weather, Geopolitics, etc.)

7. Please give suggestions to problems that you would like the Command Centre to detect and (if possible) a proposed action to the proble m. Example:
Detect: High priority order **Action**: Reserve location for order
Detect: Significant delay in shipment **Action**: Notify relevant team

5
Responses

Latest Responses
"Detect: Late priority order Action: Alternative sources of supply Detect: Bottlenec... "
"Detect: Forecasted warehouse congestion Action: notify relevant team"
"Detect: any big changes in demand, any big changes in stock for specific part#, A... "
...