BUILDING THE FOUNDATION FOR SIMULATION-BASED SUPPLY CHAIN DESIGN AT SCANIA

Olle Sandell Ferrada & Edvin Gadelii

DIVISION OF ENGINEERING LOGISTICS | DEPARTMENT OF INDUSTRIAL AND MECHANICAL SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY

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Abstract

Global manufacturing companies operate in increasingly uncertain and complex environments where changes in sourcing strategies, supplier structures and logistics networks create significant challenges for decision-making. Traditional analytical methods often struggle to capture the dynamic and interconnected nature of modern supply chains, limiting their ability to support proactive evaluation of structural changes. Simulation-based decision support offers opportunities to evaluate alternative future scenarios and understand system behavior before implementing changes. However, effective simulation requires organizational and technical prerequisites that remain insufficiently understood in industrial settings. This study investigates what is required to enable simulation-based decision support for logistics network design within a large manufacturing company.

The study was conducted as a case study at Scania's Regional Material Control Nordic organization and combined Case Study Research with Design Science Research. The research explored current decision-making practices, organizational structures and information flows related to inbound logistics and supply base changes. Data collection included interviews with stakeholders across logistics, procurement and external experts, together with internal documentation, archival records and observations. Rather than developing a simulation model, the study focused on identifying the requirements needed to enable future simulation capabilities.

The findings show that logistics network decisions are influenced by fragmented information flows, limited cross-functional visibility and insufficient data structures connecting strategic sourcing decisions with operational logistics performance. Several barriers to simulation readiness were identified, including data availability limitations, organizational disconnects and unclear ownership of required information. To address these challenges, the study developed a conceptual simulation architecture that defines required entities, key performance indicators, data requirements and organizational prerequisites. The analysis guided the creation of a simulation framework which includes a simulation readiness assessment of Scania and a five-phase roadmap outlining the activities needed to establish simulation readiness.

The study contributes to supply chain design literature by extending understanding of simulation readiness as an organizational capability rather than solely a technical implementation challenge. From a practical perspective, the findings provide Scania with a structured foundation for developing future simulation-based decision support capabilities that can strengthen proactive logistics network design and evaluation under increasing supply chain uncertainty.

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

Keywords: Simulation Readiness, Simulation-Based Decision Support, Supply Chain Network Design, Inbound Logistics, Supply Base Changes, Discrete-Event Simulation, Design Science Research

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List of Abbreviations

3PL: Third Party Logistics
ABS: Agent-Based Simulation
BEV: Battery Electric Vehicle
CSR: Case Study Research
DES: Discrete-Event Simulation
DSR/DSRM: Design Science Research / Design Science Research Methodology
FTL: Full Truck Load
KPI: Key Performance Indicator
LM: Load Meters
LTL: Less Than Truck Load
MR: Milk Run
PRU: Production Unit
PW: Pay-Weight
SCM: Supply Chain Management
SD: System Dynamics
UoA: Unit of Analysis
CO_2: Carbon Dioxide
CO_2e: Carbon Dioxide Equivalents
DC: Distribution Center
ERP: Enterprise Resource Planner
JIT: Just-In-Time
PDCA: Plan-Do-Check-Act
SCND: Supply Chain Network Design
TQDCS: Technology, Quality, Delivery, Cost, Sustainability
TL: Trunk-Load
SEU: Scania Europe
PUD: Pick-Up-Days
LACE: Landed Cost Estimation
LSM: Logistics Supplier Management
OLC: Regional Material Control Nordic
OLCAL/M/N: Material Control
OLCAT: Transport Control
OLCP: Packacking Handling, Distribution and Control
OLN: Inbound and Inhouse Logistics Development
OLNE: Flow Engineering and Network Design
OLNX: IT and Inhouse Digitalization Solutions
OLO: Logistics Centre Oskarshamn
OLS: Logistics Centre Södertälje
OP: Supply Chain Planning (Central Planning)
RMC: Regional Material Control
SCA: Scania Central Aasia
SLA: Scania Latina America

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1 Introduction

1.1. Background

We live in a time when global manufacturing companies operate in an increasingly competitive and rapidly changing business environment, facing a growing number of challenges. To ensure long-term growth, companies must remain innovative while maintaining cost efficiency (Cochran and Ramanujan, 2006). At the same time, they must manage rising uncertainty and meet high customer expectations regarding transportation times, product quality and sustainability performance (Boston Consulting Group, 2021; Tang, 2006; Abdoli et al., 2025). As a result of these continuous changes, global manufacturing companies are required to regularly reassess their strategic profiles, and the structure of their supply chains evolves accordingly (Baldwin and Freeman, 2022).

These developments have forced companies to rethink, and in many circumstances, redesign parts of their existing supply chain and logistics networks (Baldwin and Freeman, 2022; Boston Consulting Group, 2021). Such decisions are complex and often involve moving away from historical well-performing setups that are optimized for a different set of environmental conditions. For large global manufactures, changes to the supplier base, production footprint or transportation structure can result in extensive consequences for cost, service levels, sustainability performance and operational risk (Lu and Shang, 2017; Boston Consulting Group, 2021; Tang, 2006). Decision-making in this context is particularly challenging due to the complexity and interdependence of modern supply chains (Guo et al., 2024). In large-scale networks, the consequences of strategic decisions are difficult to predict beforehand, due to the fact that events between different supply chain elements may result in non-linear and delayed effects (Lu and Shang, 2017; Baldwin and Freeman, 2022; Guo et al., 2024). This limits the effectiveness of static decision-support procedures and increases the risk of unwanted outcomes when implementing structural changes.

This changing risk environment has exposed the limitations of traditional analytical tools and mathematical models for supply chain design and planning (Stefanovic et al., 2009). Classical operation research models typically rely on fixed assumptions and struggle to accurately model complex dynamic systems or predict the impacts of sudden exceptions, such as fluctuating demand or transportation delays (Stefanovic et al., 2009). Because these traditional tools and models do not adapt well to unstable conditions, they are less suitable for evaluating systemic responses to unexpected disruptions or rapid changes in business processes (Stefanovic et al., 2009). Consequently, computer simulation tools have gained increased attention as a vital approach to managing these complex decision-making situations (Stefanovic et al., 2009; Terzi and Cavalieri, 2004). Simulations enable companies to perform powerful ”what-if” analyzes, evaluating various scenarios prior to their actual implementation. By incorporating real-world uncertainty into simulation models, decision-makers can accurately assess dynamic system behavior and better understand how supply chains may respond to structural or strategic changes before implementing changes in the actual system (Stefanovic et al., 2009; Terzi and Cavalieri, 2004).

Yet, the effective use of simulation- and data driven decision-support tools requires specific organizational and technical prerequisites (Liotta, 2012; Creazza et al., 2012). Companies must have access to reliable and sufficiently granular data across the supply chain (Kuhnt and Wenzel, 2010). In a study performed by PwC it was revealed that 37% of supply chain leaders experience issues with data availability and quality as a top challenge for implementing new innovative software in its operations (PwC, 2023). Supply chain organizations must also have internal structures that enable cross-functional data sharing, and collaboration procedures that facilitate information exchange with external partners such as suppliers and logistics service providers (Creazza et al., 2012; van der Zee and van der Vorst, 2005). At the same time, rapid advances in digital technologies - such as advanced analytics, automation and artificial intelligence (AI) - are accelerating the development of more sophisticated decision-support tools for supply chain analysis and scenario evaluation, all of which require organizational readiness to create value (World Economic Forum, 2025).

In this context, a key question emerges: what is required for a global manufacturing company to adapt its supply chain and logistics network in an increasingly uncertain environment? More specifically, what organizational and technical prerequisites are necessary to effectively use simulation-based decision-support tools to evaluate and guide future supply chain configurations, without compromising competitiveness in terms of cost, quality, and sustainability?

1.2. Problem Formulation

Many industrial companies face significant challenges in translating strategic intentions into operational decision-making (Sukati et al., 2012). In particular, while concepts such as multi-sourcing, offshoring and supplier diversification are frequently discussed at a strategic level, their implications for logistics systems, transport flows and operational performance are often insufficiently understood or quantified prior to implementation (Baldwin and Freeman, 2022; Guo et al., 2024).

From a theoretical perspective, while prior research has addressed supply chain resilience, risk management, and network design, there is limited empirical work demonstrating how simulation-based approaches can be used as an integrated decision-support tool to link procurement decisions with logistics system performance (Guo et al., 2024). In particular, there is a lack of applied studies that show how changes in supplier structure can be translated into measurable impacts on transport flows and logistics operations in a real industrial context (Tang, 2006; Lu and Shang, 2017).

In light of the challenges, this thesis examines how simulation-based modeling can be enabled as a decision-support approach for evaluating changes in the supply base and their impact on logistics flows and system performance. Rather than developing a simulation model itself, the study focuses on identifying and analyzing the data, information structures, and organizational inputs required for such a model to effectively support decision-making. By investigating how changes in supplier structure, sourcing strategies and geographical configurations influence transport flows and logistics operations, the thesis seeks to clarify what type of data is necessary to capture these effects in a simulation environment.

Through a case study at Scania, the thesis aims to contribute both practically and theoretically. From a practical perspective, it seeks to support more informed and proactive decision-making by outlining the prerequisites for simulation-based evaluation of supply base changes. From a theoretical perspective, it contributes to the literature on supply chain design and decision support by providing insights into how simulation can be used to link strategic sourcing decisions with logistics system performance in complex industrial supply chains.

1.3. Purpose & Research Objectives

The purpose of this master thesis is to identify the requirements for simulating a basic supply chain network and use this understanding to create a framework of data requirements for Scania's Nordic Logistics division.

RO1: *Explore existing theoretical perspectives and best practices in industry for simulating the logistics network design.*

The first research objective provides the theoretical foundation for the thesis. It aims to explore how simulation in relation to logistics network design is addressed in existing literature and industry practice. By combining relevant frameworks and enablers for logistics network design, this step builds the theoretical perspective that guides both the empirical investigation and the developments of the final recommendations to Scania.

RO2: *Investigate how decisions regarding logistics network design are currently made at Scania.*

The second research objective focuses on empirically analyzing how such decisions are currently made within Scania. This includes mapping roles, processes, and data flows in the logistics network design. The objective is to expose gaps between different functions, potential blind spots in available information, and organizational constraints that limit the ability to predict the logistics network's operational performance. Understanding these misalignments is essential to define Scania's current limits in simulation readiness and guide the activities needed to achieve it.

RO3: *Identify challenges and limitations related to Scania's simulation readiness, and develop a framework defining the steps needed to achieve the organizational and technical requirements to enable simulation readiness for Scania's logistics network design.*

Based on insights from the theoretical review and the empirical study, the third research objective aims to define what is needed for Scania to move towards simulation readiness. This includes identifying what information, structures and competencies must be in place to allow effective modeling of the logistics network design. The resulting framework is intended to serve as a strategic roadmap for developing and implementing simulation readiness in the logistics network design.

1.4. Delimitations

This thesis focuses on the inbound logistics network within Scania's Regional Material Control (RMC) Nordic organization, which is responsible for coordinating material flows from suppliers to production units within the Nordic region. The study specifically examines the required data needed to enable simulation-based decision support in logistics network design and -evaluation.

The scope is limited to inbound material flows from Scania's suppliers to Scania's production units, including intermediate logistics nodes such as cross-docks and consolidation centers. The specific network nodes are expanded upon further in chapter 2. In-house logistics in warehouses and production units and outbound logistics flows from production units to customers are excluded, as they involve different processes, decision structures and objectives that fall outside the simulation readiness focus of this study.

The thesis does not develop or implement a simulation model. Instead, it focuses on identifying and structuring the data required to enable future simulation-based analysis. Specifically, the study aims to identify the main structural and categorical components of the inbound logistics system that would need to be represented in a simulation model. These components include physical nodes (e.g., suppliers, cross-docks, warehouses and production units), transport resources (e.g., trucks, rail and other transport modes) and flow units (e.g., components, SKUs and shipment units). For each identified category, the study examines what types of data and attributes would be required to accurately represent them in a simulation environment, what data is currently available within the organization and what critical data is missing or insufficiently structured. The thesis thereby seeks to define the necessary data structures, entity definitions and informational inputs required to enable future simulation modeling, and to identify gaps in current data availability and data collection practices that must be addressed to achieve simulation readiness.

Although supplier base changes are a central driver of logistics network reconfiguration, the study does not analyze supplier selection decisions from a procurement perspective. Rather, sourcing decisions are considered only in how they influence logistics flows and the informational requirements needed to evaluate their impact within a simulation environment. Geographically, the study focuses on the Nordic logistics network while acknowledging its integration within the broader European and global supply chain. Global supplier flows are considered only to the extent that they influence inbound logistics structures managed by RMC Nordic. Finally, the study focuses on defining structural and informational requirements at a conceptual and organizational level. Detailed operational optimization, cost modeling, and quantitative performance evaluation of specific logistics network configurations are outside the scope of this thesis.

1.5. Key Concepts

To facilitate a clear and consistent understanding for the reader, this section introduces the fundamental concepts used throughout the thesis. These concepts are inherited from both supply chain literature and internal terminology at Scania. Defining these concepts establishes an essential common vocabulary and improves overall clarity throughout the thesis.

Supply Base
The supply base is the set of contracted suppliers from which Scania sources materials, transport and other services. Its composition affects logistics flows, lead times and the structure of the supply network.

Supply Chain Network Design
Definition of the structural and strategic configuration of supply chain networks, including sourcing-, production- and distribution decisions.

Inbound Logistics
The processes, activities, and infrastructure involved in the procurement, transportation, handling, and storage of raw materials and components from upstream suppliers to Scania's production units or storage facilities.

Simulation-Based Decision Support
Simulation-based decision support refers to the use of stochastic models to replicate supply chain and logistics

systems, enabling decision-makers to systematically assess the impact of changes in sourcing, flows, and network configurations within complex inbound logistics environments.

Decision-Making Processes
Decision-making processes refer to the activities, routines, and interactions through which supply chain and network-related decisions are made. These processes involve multiple functions, both formal and informal elements, and rely on access to updated and accurate information. Their design affects responsiveness, coordination and predictability in a supply chain context.

Information Flows and Data Availability
Information flows describe how data and information moves across systems, teams and decision-making levels within the supply chain. Data availability refers to whether this information is accessible, accurate, and fit for the purpose. Gaps in data quality of flow can create misalignment, delays and reduced ability to analyze or simulate future scenarios.

”What-if” Scenarios
Analytical evaluations performed within a simulation environment to test the systemic consequences of potential operational or structural changes, such as the introduction of new suppliers or facing disruptions.

Discrete-Event Simulation (DES)
A simulation methodology that models the operation of a complex system as a discrete sequence of events over time.

Cross-dock
An intermediate logistics facility and distribution strategy where inbound shipments from multiple suppliers are received, sorted and immediately consolidated into outbound shipments toward a production facility.

Batch parts
Parts which are ordered in standard quantities and constantly stocked at Scania's storage facilities since they have stable demand and are components in most finished products. Production schedules for batch parts can be planned up to one year in advance. Batch parts are ordered in accordance with a Just-In-Time methodology, meaning that they arrive exactly when needed.

Sequence parts
Custom-made parts for specific truck configurations. Because production for custom-ordered trucks are only fixed a few weeks in advance due to the need for traceability to their designated trucks, sequence order schedules are much shorter-term than batch schedules. Sequence parts are ordered in accordance with a Just-In-Sequence methodology, meaning that they arrive exactly when needed and in the specific order required for assembly.

1.6. Structure of the Thesis

This section outlines the overall structure of the thesis, providing a brief description of each chapter and its role in addressing the research objectives.

Chapter 2: Introduction to the Case Company
This chapter provides an overview of Scania and describes the organizational context relevant to the study, with a particular focus on the Production, Procurement and Logistics function and Regional Material Control (RMC) Nordic.

Chapter 3: Methodology
This chapter outlines the research strategy and design. It explains the use of a design-science inspired case study approach and describes how data has been collected and analyzed.

Chapter 4: Literature Review
This chapter establishes the theoretical foundation of the thesis. It covers literature on supply chain management, logistics network design, and simulation-based decision support, and introduces the analytical framework used in the study.

Chapter 5: Empirical Findings
This chapter presents the results of the empirical study conducted at Scania. It includes descriptions of organizational structures, processes, decision-making practices and perceived challenges related to logistics network design and simulation readiness.

Chapter 6: As-Is Analysis
This chapter analyzes the current state of the organization based on the empirical findings and theoretical framework. It identifies key challenges related to supply base changes, simulation modeling and defines relevant KPIs for future simulation.

Chapter 7: Gap Analysis
This chapter translates the identified challenges into a structured Gap Analysis. It defines the conceptual model, specifies data requirements and evaluates current data availability in relation to the needs to enable simulation-based decision support.

Chapter 8: Simulation Framework
Based on the Gap Analysis, this chapter develops a framework outlining the organizational and technical prerequisites required to enable simulation-based decision support within RMC Nordic.

Chapter 9: Conclusion and Discussion
The final chapter summarizes the findings in relation to the research objectives, discusses theoretical and practical contributions, reflects on limitations and research quality and suggests directions for future research.

2 Introduction to the Case Company

Scania, founded 1911, is a global manufacturer of commercial vehicles such as heavy trucks and buses as well as engines, industrial batteries and related services. Scania employs approximately 59,000 people globally, serves more than 100 markets and is a part of the publicly listed Traton Group which also owns MAN, International and Volkswagen Truck & Bus (TRATON Group, n.d.; Scania, n.d.). Scania is headquartered in Södertälje, Sweden and had net revenues of 198 480 million SEK in 2025 (Scania, 2025). Their main source of revenue are truck sales, which accounted for approximately 62% of net sales in 2025 (Scania, 2025). See Figure 1 for a full breakdown of the sales mix.

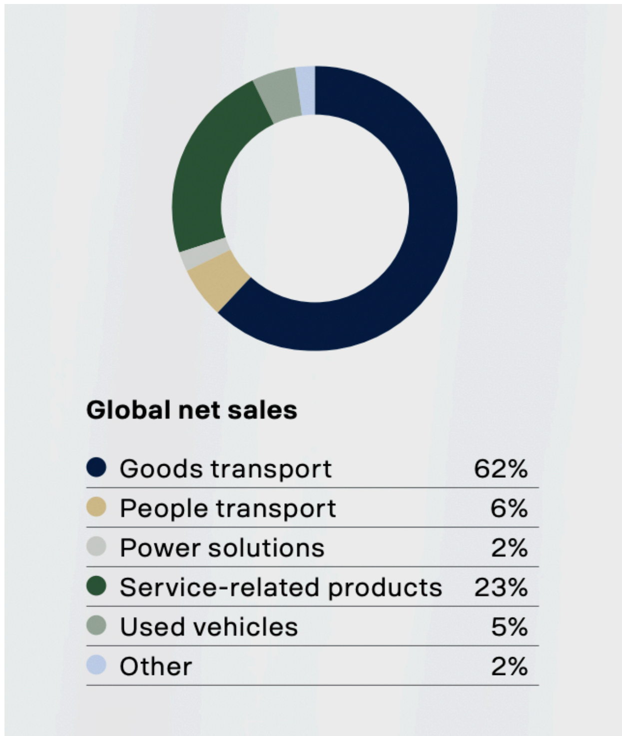

Figure 1: Breakdown of Scania's global net sales by product categories (Scania, 2025)

In this master thesis, the focus will be on the Logistics function at Scania. This function is in turn split into four different regions where the focus of this thesis will be on Regional Material Control (RMC) Nordics (See Figure 2). Scania's logistics function in the Nordic region has 700 employees, covers eight countries and handles approximately 1300 orders every day (Scania, 2025).

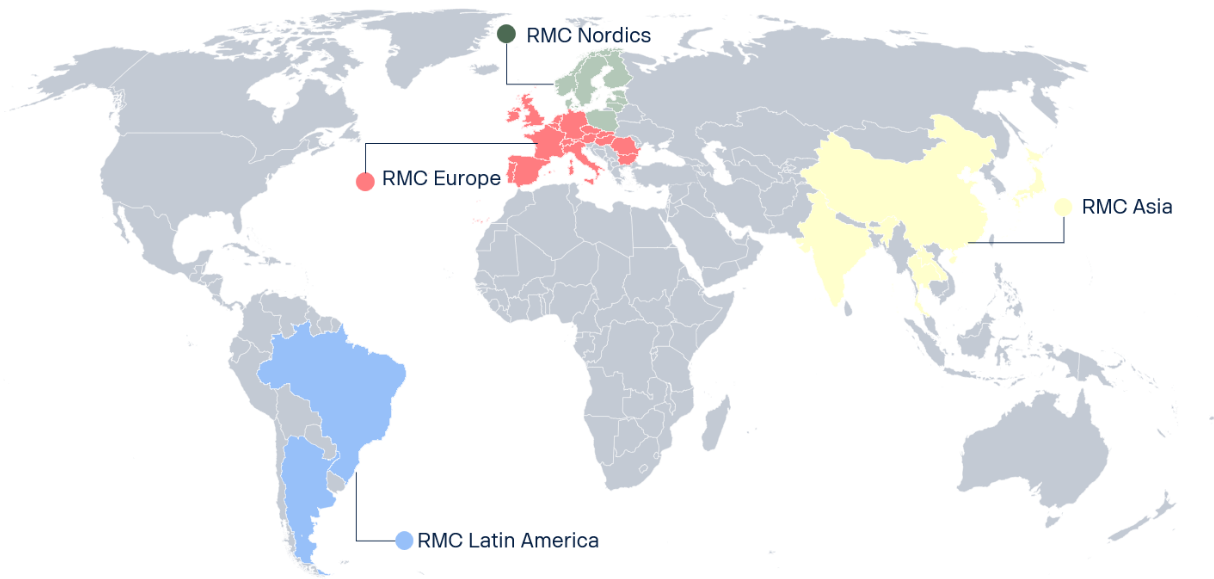

Figure 2: The four regions which Scania's Logistics function is split into. (Scania, 2025)

The Nordic region is home to four Scania production locations: Luleå, Sweden; Södertälje, Sweden; Oskarshamn, Sweden and Slupsk, Poland (Scania, 2025). The region also houses three crossdocks, approximately 400 active suppliers and handles approximately 11,500 different parts, all of which the Nordic logistics team are responsible for (Scania, 2025). The process of ordering parts, components and products from suppliers and then transporting them from suppliers to production units naturally becomes complex due to the number of available options and therefore, the scope of this thesis will be restricted to this process. A visualization of the process and scope of this thesis can be found in Figure 3 below.

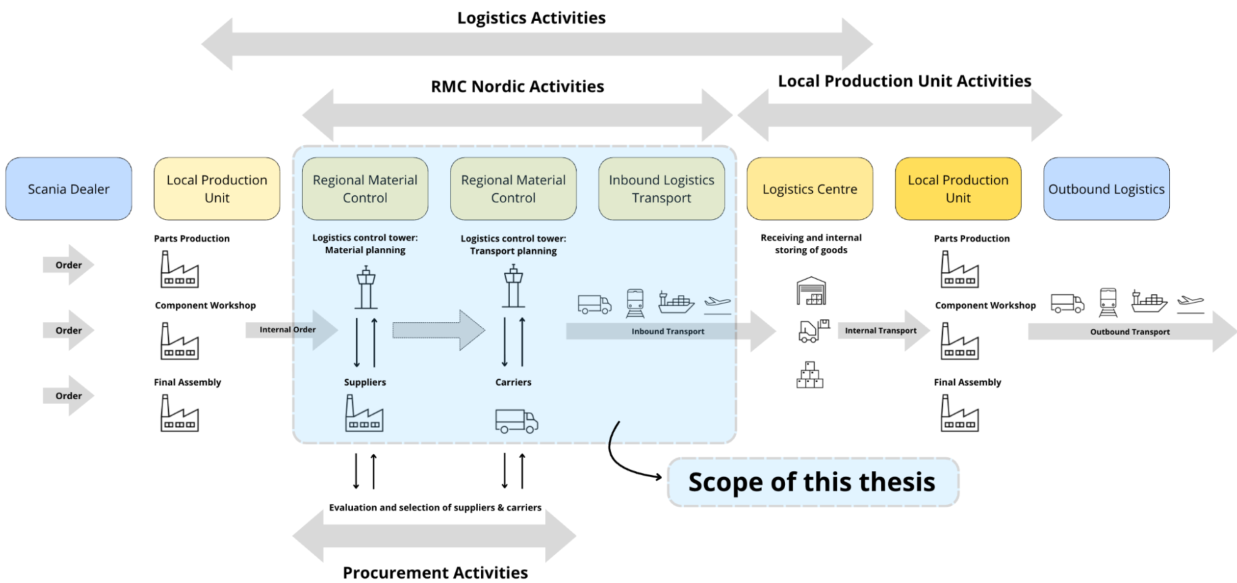

Figure 3: Process description of sequence of activities from when an order is placed to when a finished Scania product is sent to the customer.

As can be seen in Figure 3, RMC Nordic's activities are not all-encompassing for all logistics activities and both production and procurement are placed outside of the scope for this thesis. This is partly due to the organizational architecture at Scania, where these sub-functions of the Production, Procurement and Logistics function are disaggregated into separate departments with individual workstreams and responsibilities. The other reason is that the production process is very intricate with an abundance of micro-tasks and very specific processes, which will be too large of a task to record in this thesis. Procurement is deemed outside the scope mainly due to the existing limitation in the correspondence between RMC Nordics and procurement (Wigermo, 2026). As per Figure 3, the scope of the thesis will be to look at the current state of simulation readiness and the data requirements to effectively be able to model the process from transport from a supplier via a potential warehouse or crossdock to a production unit in RMC Nordic.

3 Methodology

The purpose of this chapter is to describe and justify the methodological choices made throughout the thesis. It outlines the overall research strategy, research design, and data collection methods used to address the research objectives. Furthermore, the chapter explains how empirical and theoretical insights were combined throughout the research process as well as a discussion on research quality criteria.

3.1. Research Strategy

This master thesis has adopted a combined research strategy based on case study research (CSR) and design science research methodology (DSRM). The purpose of this combination was to bridge understanding with problem-solving. Doing both enables the exploration of the current state of decision-making within Scania's logistics and procurement organization (RO2), and supports the development of a framework for simulation-based decision support (RO3). To address RO2, a single-case study approach was applied, following the recommendations of Yin (2018). Yin (2018) argues that case study research is particularly well suited for studying contemporary phenomena in their real-life context, especially when the researcher has little control over the behavioral events. This is highly relevant for this study, which aimed to understand how changes in Scania's supply base affect logistics network design decisions today. Furthermore, the focus on "how" and "why" questions aligned with the logic of case study research and provided methodological justification for selecting this approach (Yin, 2018).

To ensure theoretical contributions, the case study was designed as theory elaboration, where existing literature was used as a complement to empirical observations (Ketokivi and Choi, 2014). This approach is consistent with the "duality criterion" outlined by Ketokivi and Choi (2014), where strong case research must balance contextual stability with theoretical generalization. This dual research perspective thereby addresses both RO1 and RO3.

However, case study research alone was deemed insufficient to meet the project's final objective, which involved creating a normative artifact - in this case a framework - for enabling decision support (RO3). Therefore, the case approach was complemented with a Design Science Research (DSR) perspective, as proposed by Peffers et al. (2007). According to Peffers et al. (2007) DSR is particularly relevant in contexts involving information systems, models and prescriptive artifacts, which justified the use of this method in the thesis. Furthermore, Holmström et al. (2009) argue that DSR is effective in bridging the theory-practice gap in operations management by promoting solution-oriented thinking and enabling the development of contextually grounded artifacts. Similarly, Romme and Dimov (2021) describe DSR as a generative approach that encourages researchers to act as designers, and not merely observers, and to frame and theorize new possibilities that extend beyond existing systems. According to Peffers et al. (2007), iterative case study research pairs well with a DSR approach. Combining case study and DSR enables the study to be both empirically grounded and solution-oriented, ensuring that the developed framework model is relevant to Scania's decision context while being theoretically informed.

3.2. Research Design

The structure of the research process primarily followed the DSR logic as explained by Romme and Dimov (2021); Peffers et al. (2007), but was partially adapted to the empirical and exploratory nature of a case study in an industrial context Ketokivi and Choi (2014); Yin (2018). In line with the DSR approach, the process was divided into four main phases: Framing, Creating, Validating, and Theorizing. These were implemented in a way that ensured iteration between theory and practice, and enabled gradual development of understanding and solution. Elements of the case study logic were embedded within the Framing and Creating phases of the DSR design approach. This blended approach allowed for both deep understanding of real-life organizational conditions (CSR) and the development of practically useful artifacts (DSR). The Romme and Dimov (2021) model, its respective phases and their interdependencies can be seen in Figure 4 below.

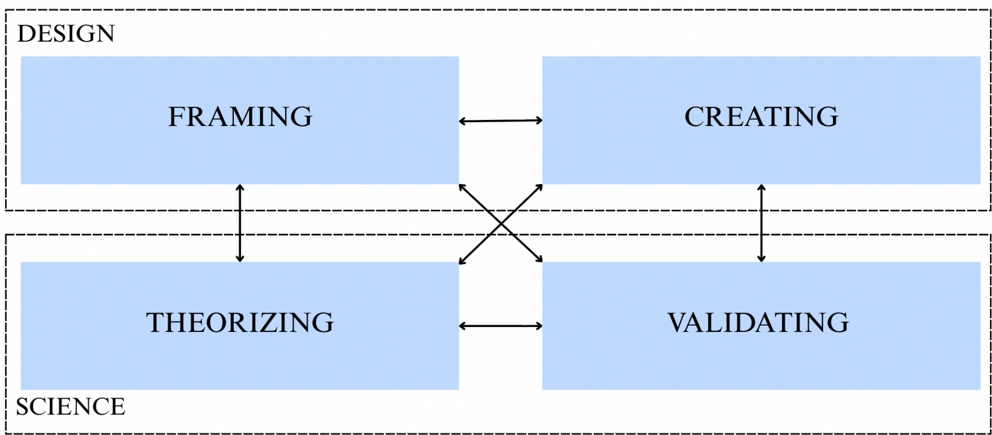

Figure 4: Romme and Dimov (2021) conceptual DSR model, with four main phases.

For this thesis, the original model was slightly adjusted in relation to the original model based on the contextual setting and resources available. The slightly adjusted model also included a version of Peffers et al. (2007)'s preliminary step of "Identify Problem & Motivate" and was represented by a "problem introduction" and "pilot study", consisting of a collaborative exploration of the problem area together with stakeholders at Scania's logistics division. The purpose of this input-step was to contextualize the topic of the thesis project, and introduce the problem as a whole. In comparison to Peffers et al. (2007)'s initial step, the corresponding step for this thesis did not include defining the final problem in itself, but rather functioned as a means to familiarize with the problem and to understand the bigger picture. The adjusted model of this thesis also differed in the sense that not all interdependencies between Romme and Dimov (2021)'s four phases were included, only the most relevant ones based on a judgment of available time and resources for this thesis project. Figure 5 illustrates the adjusted thesis research design model.

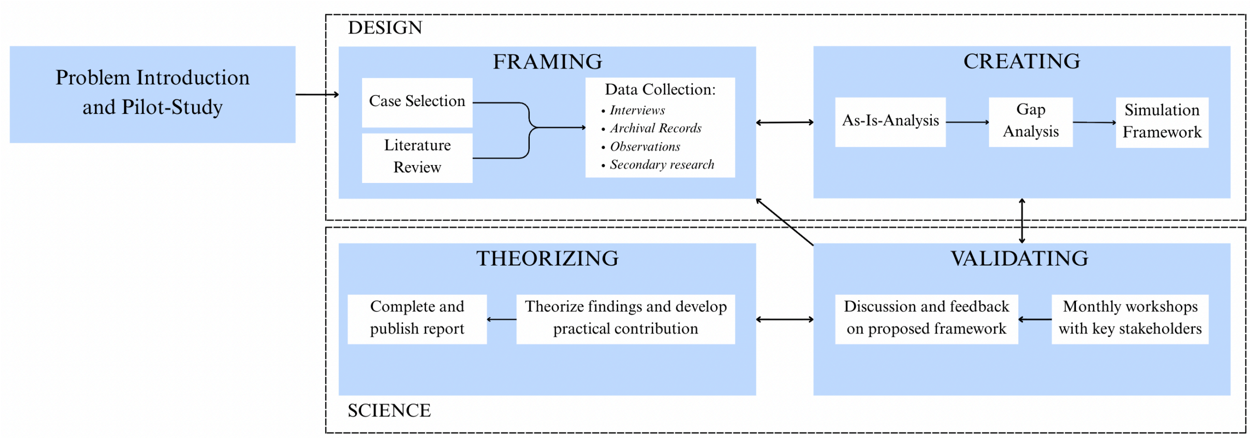

Figure 5: Adjusted research design model for a combined DSR and CSR research strategy.

3.3. Framing

Based on the input and initial problem exploration, the framing phase started off by clarifying the context, defining the specific case to analyze, and deciding the unit of analysis (UoA). This step was guided by the case study principle of contextual embeddedness, where the empirical environment is not controlled but observed, analyzed and explained in its natural setting (Yin, 2018). The literature review then framed the theoretical context and provided a basis for the interview guide which was used to conduct the interviews.

3.3.1. Case Selection

The context was set to be Scania's global logistics function, operating under increasing supply base uncertainty. During the pilot study, the concern of an increasing uncertainty in the future supply base was introduced, and key stakeholders from Scania expressed an explicit worry about not having enough insights of how this uncertainty will play out and affect the strategic and operational activities owned by the logistics function (Wigermo, 2026). The case to analyze within this context, was decided to be RMC Nordics since it delimited the project naturally from a geographical perspective and with respect to the available time and resources for this thesis. Finally, the UoA consists of the primary entity or process that is being studied, the "who" or "what" (Yin, 2018). During the problem introduction step it was made clear from Scania that the outcome of this thesis project was intended to contribute to the development of a digital decision-support tool that can support the logistics function to better understand, plan, and act on future supply base uncertainty. The outcome of the problem introduction step also clearly outlined simulation modeling as a preferred decision-support tool to explore for this specific context. Based on this, it was decided to define the UoA as the simulation readiness of the RMC Nordic organization. Rather than developing an actual simulation model, the chosen UoA was determined to be more appropriate given the limited time frame, the limited resources available and the lack of previous experience within the area of simulation modeling at RMC Nordic. Simulation in itself was also identified as not being a critical, required operational process internally by Scania. As a consequence, the UoA in the case of RMC Nordic was decided to be of exploratory character and aimed to answer the "why", "how" and "what" questions by assessing current practices, challenges and the simulation readiness of the organization (RO2).

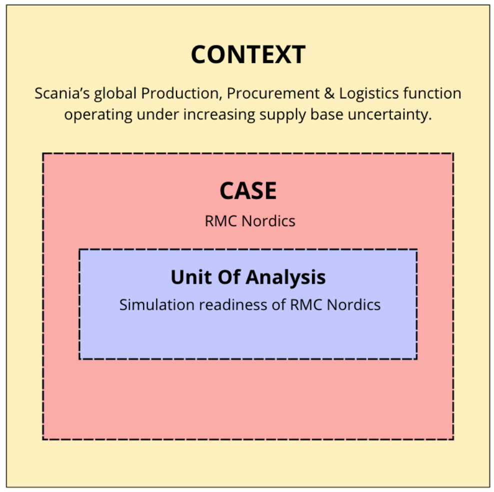

Figure 6: Definition of context, case, and UoA, according to the CSR approach (Yin, 2018).

3.3.2. Literature Review

In parallel with defining the context, case and UoA, the framing phase also included a targeted literature review focusing on three key areas: (1) supply chain management and alignment, (2) logistics network design, and (3) simulation-based decision support. The goal was to create an analytical and theoretical lens through which empirical findings could later be interpreted, in line with Ketokivi and Choi (2014)'s view of theory elaboration; using existing theory to structure the empirical research and modify it through observation. The literature also helped identify best practices and concepts used in similar industrial settings. This dual grounding in both theory and concepts used in similar industrial settings, follows the case study principle of "contextual embeddedness" (Yin, 2018).

The literature review played an important role in the research design of this thesis and was used as an integrated part of the overall research process. The literature review also supported the data collection process by summarizing important theoretical concepts, gauging the current knowledge in the field and ultimately providing the background needed to perform the data analysis. According to Knopf (2006), the literature review is treated as a work of synthesis whose purpose is not only to summarize prior research, but also to evaluate the state of existing knowledge and identify areas of consensus, disagreement and gaps. This approach supports the framing of the research problem, the positioning of the thesis in relation to existing knowledge and the identification of where the present study may contribute.

The literature review was mainly used to answer RO1, as this objective was the most detached from the case of Scania specifically. However, the literature review also supported answering RO2 and RO3, mainly indirectly through the theoretical foundation established for RO1, but also through objective sources. According to (Knopf, 2006), literature reviews are generally employed in three different contexts: either for the literature review being an end in itself to summarize the current level of knowledge in the field and what the newest findings are, being a preliminary stage in a larger research process or it can be a component in a finished research report. In this thesis, the second option was employed as a means to gain the necessary foundation for delivering theoretically grounded final recommendations. To find relevant academic sources, Google Scholar was the mainly used database. In the figure below, the most frequently used keywords can be found in Table 2

Table 2: Most frequently used keywords in the literature review.

Keywords Used	
Supply chain network design	Simulation modeling in supply chains
Logistics network configuration	Discrete-event simulation in supply chains
Inbound logistics	Scenario analysis
Supplier base structure	What-if analysis
Supply chain decision-making	Supply chain resilience
Cross-functional coordination	Data availability and information flows
Simulation-based decision support	

In addition to academic sources, Knopf (2006) encourages the use of other sources such as government agencies, international governmental organizations, non-governmental organizations, think tanks, and independent, freelance researchers. These sources should be used to fill in gaps where academic research doesn't have an answer, where context simply needs to be established or to gather the latest information, which may not be available in any other sources. Knopf (2006) does however press the importance of authors to use these sources with great caution as they aren't peer-reviewed. Therefore, these types of sources were used sparingly and primarily to set context.

The literature review was used iteratively throughout the research process. During the framing phase, it supported the formulation of the research objectives and the development of an analytical perspective. As empirical findings emerged from the case study at Scania, insights from the literature were revisited and refined, enabling theory elaboration rather than theory testing. This iterative use of literature aligns with Knopf (2006)'s view that literature reviews in applied research should help position new findings in relation to existing knowledge and clarify the contribution of the study.

3.3.3. Data Collection

Since one of the main purposes of the framing phase is to explore and understand a problem, it is of highest interest to analyze different types of data related to the specified case and context (Romme and Dimov, 2021). Given the exploratory nature of the defined UoA, the data collection phase was an important and central part of this case study. It provided the empirical foundation for understanding how supply base and logistics network design decisions were currently made at Scania and what organizational and informational prerequisites are required to enable simulation-based decision support. According to Yin (2018), robust case study research should be based on multiple sources of evidence in order to capture complex real-life phenomena and strengthen the credibility of findings. In line with this guidance, the data collection in this thesis combined multiple qualitative data sources, complemented by quantitative and archival material where relevant.

Given the exploratory nature of the research and the focus on understanding how and why decisions are made, the study primarily relied on qualitative data. Quantitative data was not used for modeling purposes, but rather supported contextual understanding and illustrated the type of information that would be required for future simulation-based analyses. This choice was closely aligned with the purpose of the thesis, which was not to develop or validate a simulation model, but to identify the prerequisites to enable such a model in practice. The data collection consisted of four main categories:

1. Archival Records and Internal Documentation
2. Interviews
3. Observations and Informal Interactions

Interviews constituted the primary data source and were complemented by internal documents and limited quantitative material to triangulate findings and enhance contextual understanding. Triangulating findings from different sources also reduced exposure to the risk of sources being biased (Yin, 2018). The combination of data sources supported a holistic understanding of decision-making processes, information flows, and organizational interfaces related to changes in the supply base and inbound logistics network.

3.3.3.1. Archival Records

The archival records collected and analyzed for this thesis project primarily consisted of Microsoft (MS) Excel files, Power BI reports, MS PowerPoint files and MS Word documents. The Excel files accessed were mainly tools currently used to support decision-making related to the design of the inbound logistics network. In this thesis, these tools were assessed and analyzed to understand the current processes of monitoring, evaluating and configuring the inbound logistics network. Furthermore, the archival records also served to give an understanding of Scania's organizational structure within the functions relevant to the context of this thesis. The study of archival records was conducted to address RO2. Table 3 presents an overview of the archival records studied in this thesis.

Table 3: Archival records analyzed in this thesis.

Type of Archival Record	**Description of Archival Record**
Power BI	Dashboards and reports used for visualizing logistics performance and extracting data from the data lake.
MS Excel	Internal tools currently used for simulation, scenario analysis, optimization and “what-if” evaluations.
MS PowerPoint	Presentation material including organizational charts and descriptions of selected work functions.
MS Word	Internal standards and guidelines, including instructions on how to perform specific tasks and processes.

3.3.3.2. Interviews

In this thesis, the most critical part of the data collection phase was conducting interviews with various stakeholders. These interviews were primarily carried out to address RO2. The interviews served as the foundation for the current state analysis, with the overall aim of identifying and understanding the main challenges for RMC Nordic to start using simulation as a decision-support tool. This approach allowed for an interactive process, where follow-up interviews coould be held if clarification or deeper insights were needed. The outcomes of the interviews provided qualitative data that supported the definition of current challenges (RO2) as well as contributed to the development of the proposed framework (RO3).

To achieve structure and clarity throughout this phase, and given Scania's organizational structure, the interview subjects were divided into three categories. While the thesis was limited to the Nordic region, interviews with Scania and TRATON employees from other regions (e.g., Brazil, the Netherlands, and Germany) were also held to explore whether simulation tools were already in use in a similar contexts relevant to RMC Nordic's needs.

The first category (A) included employees within the RMC Nordic organization, and focused primarily on inbound logistics activities. As this category formed the core of the thesis scope, these interviews were conducted first. These interviews aimed to provide an understanding of how changes in the supply base affects decision-making for RMC Nordic's inbound logistics network design. Additionally, the interviews helped identify the availability and structure of data. Interviewees ranged from senior directors and group managers to operational staff.

The second category (B) consisted of the procurement division within Scania. Procurement plays a central role in sourcing suppliers and shaping the structure of Scania's supply base. These interviews focused on understanding the interaction between RMC Nordic and the procurement division, and how this relationship influences the decision-making related to inbound logistics network design (RO2). A key objective was to identify potential blind spots or misalignment in this relationship that may hinder the adoption of simulation tools.

The third category (C) included external actors. This category consisted of consultancy firms with experience in supply chain simulation and optimization, logistics professionals with experience in using simulation tools to aid decision-making and academic experts such as professors and researchers in the field. The purpose of these interviews were to gain insight into typical requirements for effectively implementing simulation tools in practice and common challenges that companies face when implementing them.

In company-based case studies, the total number of interviews performed is often limited due to time and resources constraints on the part of the organization Kembro (2026). The structure of the interviews for Category Logistics and Procurement, were semi-structured, which mixes open-ended questions and fixed questions with limited response options. Two separate interview guides were created for each category, and their questions and discussion areas were adjusted to the different functional areas of responsibility and their relation to the research objectives. The main purpose of employing this structure was to gather insights and responses from the interviewees. Semi-structured interviews allow for a set of supporting questions while maintaining flexibility in the order and phrasing of questions, depending on the interview situation (Höst et al., 2006).

For the third category, consisting of External Parties (C), the interviews were conducted with a more open structure and the interview guide included less standardized questions. Instead, it included themes connected to the simulation readiness of supply chain organizations. The focus of these open-ended interviews was to explore the area qualitatively and in depth, to provide a foundation for RO1 and support the proposed framework in RO3. This open structure allowed the interviewees to largely guide the discussion within the predefined discussion themes (Höst et al., 2006).

Each interview guide can be found in the Appendix section at the end of the report, and they are marked as *Interview Guide - Logistics*, *Interview Guide - Procurement*, and *Interview Guide - External Parties*. In Table 4 below, an overview of the interview categories can be found, together with their main focus area and their interview structure. In the ”Interviewee” column in Table 5, the subscripts ”i” and ”e” indicate whether an interviewee is internal or external respectively.

Table 4: Overview of used interview guides.

Interview category	**Structure**	**Number of Interviewees**
A: Logistics	Semi-structured	17
B: Procurement	Semi-structured	3
C: External Parties	Semi-structured / Open-ended	4

Table 5: List of interviewees with respective purpose and date.

Interviewee	**Role at company**	**Purpose**	**Length**	**Date**
A_i	Group Manager, Logistics Supplier Management (LSM)	Understand how supplier audits and evaluation processes are conducted, and how supplier performance is assessed and used to support decision-making in the inbound logistics context.	1h	2026-02-26
B_i	Group Manager, Global Material Controller	Understand the role, processes and challenges of material planning, and how these influence coordination of material flows and operational logistics performance.	1h	2026-02-27
C_i	Traton Strategy Manager	Understand logistics network design and integration processes across Traton.	1h	2026-02-27

Interviewee	**Role at company**	**Purpose**	**Length**	**Date**
D_i	Group Leader, Supply Chain Engineering, Scania Europe (SEU)	Understand SEU's perspective on logistics network design, supplier selection processes and data-related challenges, as well as how these limit simulation use and proactive planning.	1h	2026-02-27
E_i	Group Manager, Global Inhouse Logistics Development	Understand how supplier selection, decision-making processes and how sourcing decisions impact inhouse logistics.	1h	2026-03-02
F_i	Head of Regional Material Control Nordic	Understand how material control operations manage supplier changes, ensure delivery performance and handle disruptions, as well as limitations in proactive network planning.	1h	2026-03-02
G_i	Group Manager, Supply Chain Engineering, Scania Latina America (SLA)	Understand SLA's perspective on logistics network design, supplier selection processes and data-related challenges, as well as how these limit simulation use and proactive planning	1h	2026-03-02
H_i	Senior Supply Chain Developer	Understand inbound network design and challenges related to supplier base changes, and Traton integration and joint transport network development.	1h	2026-03-03
I_i	Head of Logistics Nordic	To understand strategic perspectives on inbound logistics development and how large-scale structural changes influence network design and future decision-making needs.	1h	2026-03-03
J_i	Head of Inbound and Inhouse Logistics Development	To understand strategic perspectives on inbound logistics development and how large-scale structural changes influence network design and future decision-making needs.	1h	2026-03-03
K_i & L_i	Supply Chain Developer	Understand how inbound network design and flow engineering are carried out operationally, including practical challenges, decision processes and how changes in the supply base are managed in daily work.	1h	2026-03-03

Interviewee	Role at company	Purpose	Length	Date
M_i	Suppler Chain Developer, MAN	Understand MAN's perspective on network design, including challenges related to supply base changes and the role and potential of simulation in decision-making.	1h	2026-03-04
N_i	Group Manager, Logistics Development	Understand how supply base changes impact inhouse logistics and factory feeding operations at the logistics center.	1h	2026-03-04
O_i	Group Manager, Inbound Logistics IT and Digital Solutions	Understand IT capabilities and digital prerequisites for enabling simulation-based decision support in inbound logistics.	1h	2026-03-05
P_i	Group Manager, Inbound Network Design and Flow Engineering	Understand how inbound network design and flow engineering are managed at a group level, including decision processes, responsibilities and key challenges in designing the logistics network.	1h	2026-03-05
Q_e	Senior Data Scientist, Simulation Modeling at Amazon	Understand practical simulation requirements, modeling approaches and data needs from an external expert perspective.	1h	2026-03-09
R_e	Simulation Lecturer and Researcher at Chalmers University of Technology	Understand practical simulation requirements, modeling approaches and data needs from an external expert perspective.	1h	2026-03-10
S_i	Senior Advisor, Global Procurement	Understand procurement's perspective on supplier selection, supply base decisions and future strategic sourcing	1h	2026-03-10
T_e	External Supply Chain Simulation Expert/Consultant	Understand practical simulation requirements, modeling approaches and data needs from an external expert perspective.	1h	2026-03-10
U_i	Sourcing Manager, Scania Central Asia (SCA)	Understand SCA's procurement perspective on supplier selection, supply base decisions and future strategic sourcing.	1h	2026-03-11
V_e	Supply chain simulation consultant at Optilon	Understand practical simulation requirements, modeling approaches and data needs from an external expert perspective.	1h	2026-03-11

Interviewee	Role at company	Purpose	Length	Date
W_i	Supplier Quality Engineer	Understand how supplier quality considerations influence supply base decisions and how these impact inbound logistics performance and network design.	1h	2026-03-11
X_i	Senior Sourcing Manager	Understand procurement's perspective on supplier selection, supply base decisions and future strategic sourcing	1h	2026-03-13

3.3.3.3. Observations

The data collection phase of the thesis project also included observational studies. These consisted of an on-site visits to the inhouse logistics center at the chassis assembly plant in Södertälje. The visit was guided and primarily contributed to addressing RO2, as it enabled direct observations and potential analysis and inclusion of critical flows typically considered in logistics simulation models, and therefore helpful for achieving RO3.

3.4. Creating

The *Creating* phase combines case study data analysis with artifact design, consistent with the dual goals of understanding, intervention and creativity (Yin, 2018). Empirical data from the study was primarily gathered through interviews with key stakeholders across the different interview categories. This phase also included analyzing the insights from observations, operational processes, and internal documentation. These are techniques commonly associated with CSR (Yin, 2018; Höst et al., 2006). The aim was to map current decision-making processes, information structures, and cross-functional interactions, particularly those related to changes in the supply base and logistics network design. The Creating phase was divided into three analytical steps: As-Is Analysis, Gap Analysis, and Simulation Framework development. Each step built on the previous one to progressively move from understanding the current state to defining a guiding framework for simulation readiness for RMC Nordic. An overview of these steps is presented in Figure 7

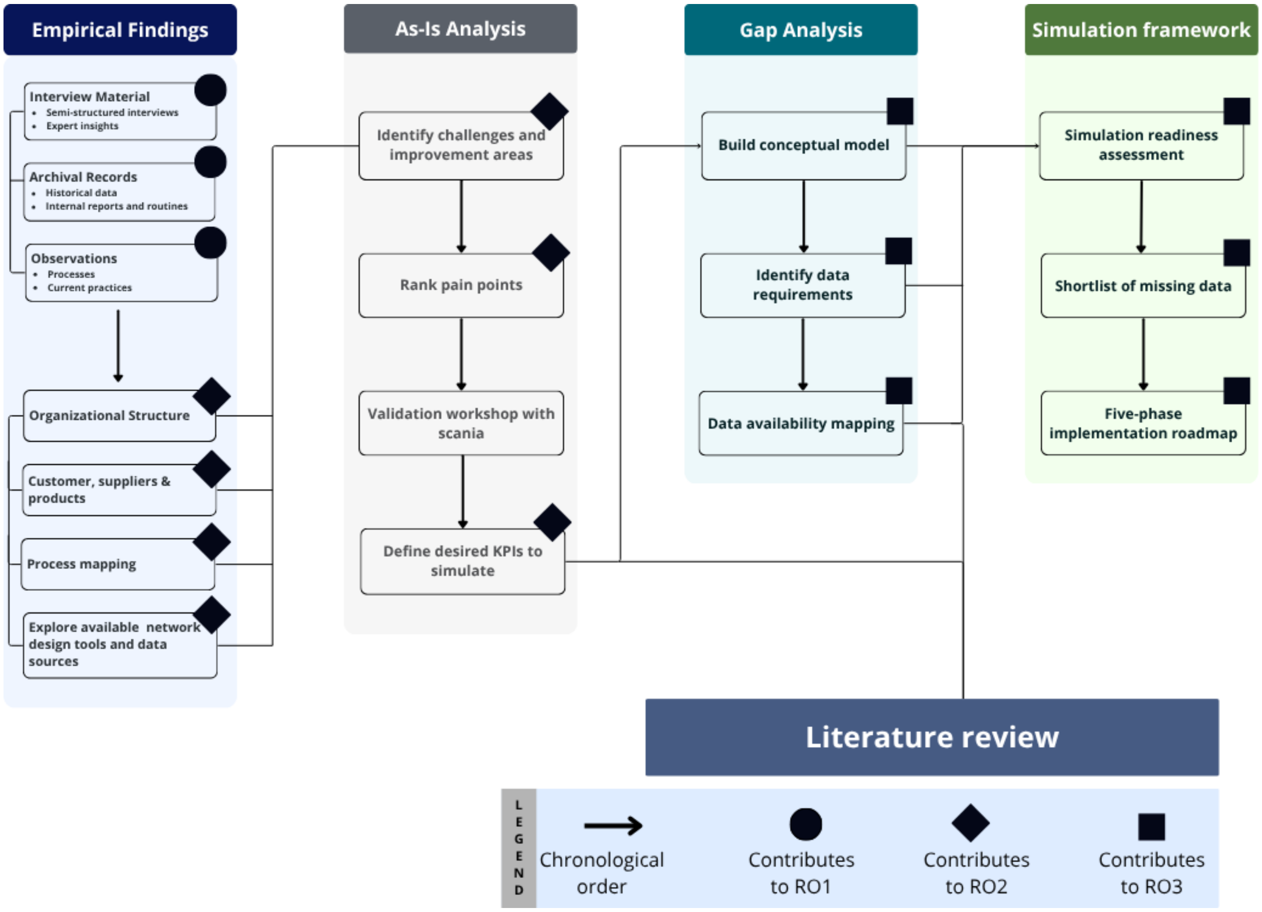

Figure 7: Overview of the analysis steps carried out in the Creating phase.

3.4.1. As-Is Analysis

The As-Is Analysis synthesized the empirical findings from the data collection phase and constructed a comprehensive understanding of how supply base and logistics network design decisions are currently made in RMC Nordic. The foundation for this analysis step was primarily qualitative data in the form of interviews, but also included insights gathered from observations and internal documentation to enhance triangulation across different data sources and hence validated findings and strengthened the evidence for key conclusions.

According to Höst et al. (2006), qualitative data analysis can be divided into four steps and these are Gathering, Coding, Grouping and Conclusions. The Gathering step reflects that conducted interviews were collected with the help of Microsoft Team's built-in Copilot functionality. The interview material was recorded and transcribed automatically, and this allowed for conducting a large amount of interviews in comparison to if the transcribed interview material would have needed to be transcribed manually, due to the realized time savings. To perform the actual analysis, the transcribed interview material was reviewed with relevant patterns and messages were coded (Coding) and grouped (Grouped) to efficiently summarize what different interviewees expressed regarding key topics (Höst et al., 2006). Based on the outcome of the grouped interview material, the As-Is Analysis was structured around four sequential activities:

1. **Identify challenges and improvement areas:** Analyzed the collected empirical data to identify key weaknesses and areas for improvement in RMC Nordic's inbound logistics network.

2. **Rank pain points:** Evaluated and selected the most appropriate identified challenges based on their suitability and feasibility from a simulation-based decision support perspective.

3. **Validation workshop with Scania:** Presented the prioritized list of challenges to key stakeholders. The purpose of this workshop was to ensure that the problem was clearly defined and grounded in a relevant real-world context before moving on to the modeling phase.

4. **Define desired KPIs to simulate:** The As-Is Analysis was concluded by explicitly defining specific KPIs that the conceptual simulation model had to eventually capture to properly evaluate the selected challenge.

3.4.2. Gap Analysis

Holmström et al. (2009) define Means-Ends Analysis as the "*representations of present states, desired states, the differences between the two states, as well as the actions that change the present situation.*" In this thesis, The Gap Analysis aimed to achieve this by comparing the current situation, from the As-Is Analysis, to the future requirements needed to effectively be able to model and implement an appropriate simulation tool. To execute the Means-Ends Analysis, the Gap Analysis was divided into three sequential steps:

1. **Build conceptual model**: A highly simplified system description of the inbound logistics network was developed. This conceptual model was intended to be the base for the next steps.

2. **Identify data requirements**: The next step consisted of specifying the exact data attributes and parameters that are necessary to accurately represent the conceptual model and calculate the defined KPIs.

3. **Data Availability Mapping**: The final step of the Gap Analysis was performed by mapping the actual operational data currently available within RMC Nordic's systems against the identified data requirements. The purpose of this step was to identify potential data gaps and evaluate the overall availability, accessibility and quality of the required data. To ensure a structured and representative mapping process within the project's time frame, a specific region with high data availability within RMC Nordic's network was selected as the primary baseline for this evaluation. The choice of this region was based on the empirical findings.

3.4.3. Simulation Framework

Based on the outcomes of the Gap Analysis, a simulation readiness framework was developed. The framework translated the actions needed to move from the current situation toward a state where simulation can function as an effective decision-support tool for logistics network design at RMC Nordic. The framework addressed both dimensions identified in the Gap Analysis: the data and information acquisition requirements, and the organizational prerequisites needed to enable adoption and value creation. It was therefore intended to serve as a practical "roadmap" that Scania can use to assess their readiness and prioritize the necessary preparations before implementing simulation-based decision support. The Simulation Framework works as a prescriptive artifact that remains applicable regardless of which software is ultimately chosen and was divided into three components:

1. **Simulation readiness assessment**: Evaluation of RMC Nordic's current state across technical readiness, organizational readiness and the perceived strategic value of simulation.
2. **Shortlist of missing data**: Summary of the crucial data points that are missing or lacking sufficient quality during the mapping process, and formulation strategies to retrieve and structure this data.
3. **Five-phase implementation roadmap**: Presentation of proposed step-by-step approach designed to guide RMC Nordic from its current baseline toward establishing an operational simulation capability.

3.5. Validating

In this phase, the steps in *Framing* and *Creating* were iteratively validated in dialogue with Scania stakeholders. Rather than testing a technical artifact, the validation focused on assessing the relevance, completeness and organizational feasibility of the proposed solutions, requirements and structure. The feedback was collected through stakeholder workshops. This process aligns with Yin (2018)'s notion of continuous case validation, where findings are shared and refined within the case environment rather than externally validated through replication. Importantly, validation was not treated as a single event but as an iterative feedback loop, meaning that the framework was adjusted based on stakeholders comments and insights, ensuring both contextual grounding and internal acceptance. This phase also served to uncover final insights about organizational dynamics that were not visible during the initial data collection.

3.5.1. Monthly Workshops

During the project, four monthly workshops were conducted with the Head of Inbound and Inhouse Logistics Development, the Group Manager of Inbound Network Design and Flow Engineering and the Scania thesis supervisors. The purpose of these workshops served to validate and guide the development of the artifact, to ensure alignment on project goals and to gain outside perspectives on the project's development. During the workshops, the participants were updated on the latest changes since the last workshop, the planned activities going forward, developments were demonstrated and general project direction was discussed. The feedback received during the workshops was then used to revisit the *Framing* and *Creating* phases to correct, adjust or create new actions needed.

Table 6: Overview of monthly workshops, including intended purpose and actual outcomes

Workshop	Date	Purpose
Workshop 1	2026-01-23	The purpose was to define an appropriate thesis project scope based on insights from the first week of the on-site pilot study at Scania. The outcome was alignment on conducting an in-depth interview study to better understand suspected challenges related to the future supply base. Based on these findings, the project direction was set to explore how these challenges could be addressed using simulation-based decision support, as well as to assess RMC Nordic's readiness in relation to the required prerequisites.
Workshop 2	2026-02-20	The second workshop included a presentation of the proposed interview groups, selected interviewees and drafted interview guides for each category.
Workshop 3	2026-03-20	The purpose of the third workshop was to present the initial findings from the interview study. This included summarizing the identified challenges and improvement areas from the As-Is Analysis, as well as defining the desired KPIs together with key stakeholders at Scania.
Workshop 4	2026-04-24	Based on the direction defined during Workshop 3, the results from the Gap Analysis were presented. This included presenting the conceptual model, an initial data availability mapping and the overall simulation readiness of RMC Nordic.
Workshop 5	2026-05-17	The finalized Simulation Framework was presented and discussed, and a draft of the final presentation of the entire thesis project was presented and discussed. Feedback from Scania stakeholders was used to make final adjustments.

3.6. Theorizing

The final phase linked the empirical and design outputs back to the research objectives and theoretical context. Here the framework was positioned as both a practically useful artifact and a theoretical contribution to existing literature on supply chain decision-making and simulation readiness. This reflects DSR's core purpose to bridge the gap between understanding and intervention (Holmström et al., 2009), and to enable the researcher to act as a "designer" rather than just a passive observer (Romme and Dimov, 2021). The practical contribution lied in clarifying what Scania would need - in terms of data, roles, structure, etc. - to develop future simulation models for logistics network design. The theoretical contribution was an elaboration of existing literature on decision-making under uncertainty and simulation-based planning in industrial supply chains. It demonstrated how theory can be adapted to real-world complexities, and how structured artifacts can be used to align strategic and operational perspectives.

3.7. Research Quality

Demonstrating robust findings and a sound scientific method is an important part of conducting research (Peffers et al., 2007). To ensure that the quality of the research can be trusted, demonstration of the quality and credibility should be included in the research process itself (Denscombe, 2010). Traditionally, logistics research has been primarily judged on quantitative criteria such as validity, reliability and objectivity, and claims in such research have been evaluated against ”true and objective correspondence” with reality (Halldórsson and Aastrup, 2003).

The traditionally used evaluation criteria have been criticized for not incorporating the necessary qualitative elements that are relevant in contemporary logistics research and Halldórsson and Aastrup (2003) therefore argue that logistics research quality should instead be judged by the four criteria: credibility, transferability, dependability and confirmability. Halldórsson and Aastrup (2003) claim that several trends in logistics research exhibit a departure from the positivistic paradigm towards multi-paradigmatic research. They mention several cases where logistics research have complemented quantitative methods with qualitative methods in the form of interviews and focus groups. As this thesis used a combined approach where empirical data was collected both through interviews, observations and archival records, the suggested criteria of credibility, transferability, dependability and conformability was utilized.

Credibility is - similarly to the conventional *internal validity* - viewed as the ”truth-value” of the research findings (Halldórsson and Aastrup, 2003). However, the view of credibility relies on the belief that there is no such thing as a singular objective reality, but rather if the respondents view of reality align with the theoretical view of reality (Halldórsson and Aastrup, 2003). In this thesis, credibility was ensured through triangulation by comparing answers from interview responses internally from Scania employees as well as interview responses from external experts along with archival records and theoretical knowledge. Triangulation is defined as viewing things from more than one perspective, which can mean the use of different methods, data sources or different researchers within the study (Denscombe, 2010).

Transferability is ”the extent to which the study is able to make general claims about the world” (Halldórsson and Aastrup, 2003). This corresponds to the traditional view of *external validity*, where generalizability across the population can be established with a certain level of confidence. The vulnerability with the traditional approach to generalization is that it does not take into account that even if the findings are only meant to guide decisions in the same context, the operational context and the people that comprise that context will both be subject to change as time passes (Denscombe, 2010). Halldórsson and Aastrup (2003)’s transferability criterion tackles this by placing greater emphasis on the transferability between different contexts rather than generalization of a specific context. This was achieved by providing the reader with the context of the case company, current situational context and discussing the implications of this to the transferability, ultimately letting the reader form their own opinion on the transferability of the findings.

Dependability corresponds to the traditional *reliability* criterion, which is defined as the stability of the data over time (Halldórsson and Aastrup, 2003). This means that replication of the same or similar conditions should generate the same measurements. While the traditional view of reliability is sensitive to alterations in methodology or solution architecture, the dependability criterion is not as strict when it comes to stability

(Halldórsson and Aastrup, 2003). Instead, the dependability criterion places larger emphasis on traceability, since changes in research design and constructs during the project are to be expected. The dependability criterion therefore requires clear documentation of changes to ensure that dependability of the study can be easily audited (Denscombe, 2010; Halldórsson and Aastrup, 2003). In this thesis, dependability was ensured by clear documentation of the underlying logic of the proposed simulation model framework and clearly stating the origins of source material or necessary assumptions.

Confirmability corresponds to the traditional quality criterion *objectivity*, which is the extent to which the findings of the research are based on the results of the methodology rather than the bias of the researcher(s) (Halldórsson and Aastrup, 2003; Denscombe, 2010). The confirmability criterion places greater emphasis on the extent to which the findings can be confirmed through the data itself (Halldórsson and Aastrup, 2003). Confirmability was achieved through basing the analysis on the collected data, meaning that findings can be back-tracked in order to audit the extent to which the authors biases have affected the findings. See table 7 for a summary of the quality criteria used and how this thesis covers them.

Table 7: Research quality criteria and application

Quality criterion	**Description**	**Application in this thesis**
Credibility	The ”truth-value” of the research findings	- Triangulation - Multiple, independent sources - External Interviews
Transferability	Extent to which findings translate to other contexts	- Case company description - Situational context description - Transferability discussion
Dependability	Traceability of methodology and procedure	- Documented logic architecture - Clearly stated sources - Clearly stated assumptions
Confirmability	Unbiasedness of findings	Analysis based on collected data

4 Literature Review

This chapter lays the theoretical foundation for the thesis and is structured around three main literature areas. First, supply chain management, alignment and decision-making is explored. Second, logistics network design is covered before moving to the last area - simulation-based decision support. The three areas are summarized in Figure 8, which showcases all the literature areas and what research objectives they address.

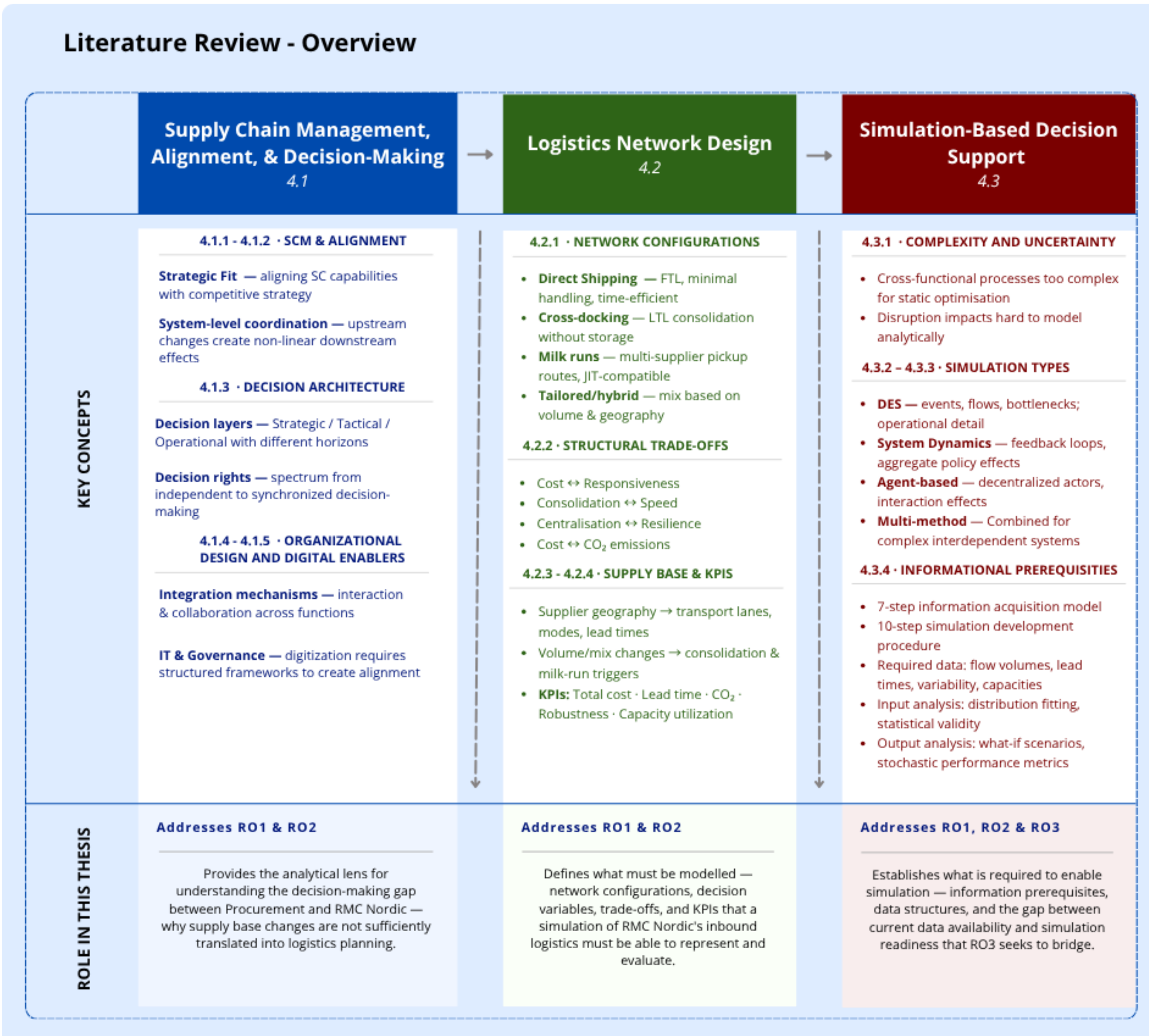

Figure 8: Summary of literature review

4.1. Supply Chain Management, Alignment and Decision-Making

This literature addresses how supply chain organizations manage cross-functional coordination, information flows and decision-making across functions. It provides a theoretical basis for analyzing how changes, such as shifts in the supplier base, are initiated, communicated and aligned across the organizations, and how the lack of alignment can reduce the predictability of the effects throughout the supply chain.

4.1.1. Supply Chain Management

A foundational perspective in supply chain management (SCM) is that performance should be understood at the system level, not only at the level of individual functions or firms. In one widely used definition, SCM is framed as the "system, strategic coordination" of traditional business functions and tactics across firms in a supply chain with the goal of improving performance for each firm and the chain as a whole (Prajogo and Olhager, 2012). This view is highly relevant for industrial companies where functions such as procurement, manufacturing and logistics are tightly related but often managed with different objectives and planning horizons.

From a managerial perspective, SCM is frequently described as an integrated flow challenge of coordinating material, information, and financial flows to fulfill demand and enhance competitiveness (Dias and Ierapetritou, 2017). How this integrated flow is framed matters, because it has been shown that when one supply chain upstream condition changes, downstream effects often spreads through multiple interacting flows and local functions (Dias and Ierapetritou, 2017).

In classical SCM strategy contexts, this system-level way of thinking is often implemented through the logic of strategic fit i.e., aligning supply chain capabilities and configuration with the overall corporate competitive strategy (Chopra and Meindl, 2013). A key implication for network-related decisions is that supply chain design and logistics network planning should not be treated as isolated exercises. Achieving strategic fit requires coordination across functional strategies and alignment of processes, resources, and the roles of supply stages. If this isn't fulfilled, functions may take conflicting actions that reduce overall supply chain performance (Chopra and Meindl, 2013). Within SCM praxis and literature, it is often assumed that responsiveness drivers - such as service level and lead time - are linked to cost and uncertainty. These performance drivers must be managed as interdependent trade-offs rather than independently optimized (Chopra and Meindl, 2013; Lundin and Norrman, 2010).

4.1.2. Supply Chain Alignment

Supply chain alignment can be explained as the degree to which objectives, processes and information are mutually consistent across functions within a firm and across supply chain partners (Wong et al., 2012). This approach is consistent with the broader SCM view that effective supply chain management requires "*systemic strategic coordination*" across traditional business functions, rather than optimization within isolated silos (Mentzer et al., 2001). Chopra and Meindl (2013) further illustrate that misalignment across functions can lead to conflicting actions and reduced overall supply chain performance. This reinforces that performance drivers must be managed as interdependent trade-offs (Chopra and Meindl, 2013).

Coordination research specifies that alignment is implemented through clear and specific coordination structures. In particular, it is stated the following should be regarded; (i) how decisions rights are allocated and synchronized, (ii) how information is shared, and (iii) how incentives and performance measures are designed to support system outcomes rather than local optimization (Simatupang and Sridharan, 2005). This becomes especially critical because supply chain decisions cover strategic, tactical, and operational aspects and sequential or fragmented decision-making across the aspects can produce suboptimal or infeasible outcomes, motivating integrated decision strategies (Dias and Ierapetritou, 2017).

Through SCM research it has also been shown that supply chain alignment depends on both technical connectivity and relational mechanisms. This implies that information integration requires digital- and IT linkage but also willingness and capability to share information relevant for strategic and operational decisions (Prajogo and Olhager, 2012). Wong et al. (2012) further reasons that information-sharing quality (relevance, accuracy, sufficiency, punctuality) and appropriate performance measurements systems are key enablers of alignment Wong et al. (2012). Moreover, SCM organization research highlights that supply chain alignment is shaped by organizational design choices, such as centralization vs decentralization trade-offs, intended to manage cross-functional interdependencies and complexity (Nakano, 2020).

4.1.3. Decision-Making Levels in Supply Chain Organizations

A constantly relevant theme across decision-making literature is that supply chain decisions exist across interdependent layers with different time horizons and levels of detail (Dias and Ierapetritou, 2017; Simatupang and Sridharan, 2005). Different decision types, their typical time horizons and actions can be found in Table 8 below.

Table 8: Types of supply chain decisions and their characteristics.

Type of Decision	Time Horizon	Level of Detail
Strategic	Years	- Network configuration - Capacity allocation
Tactical	Month/Quarters	- Resource allocation - Medium-term plans
Operational	Days/Weeks	- Day-to-day governance over operational processes.

A key problem in many supply chain organizations is that decisions are still made in a sequential manner (top-down, layer-by-layer), where upper-level decisions are made with limited input from lower-level realities. Such sequential approaches can produce suboptimal, infeasible or unpredictable outcomes and motivate the need for integrated decision-making frameworks (Dias and Ierapetritou, 2017).

Research on decision-making and coordination structures within supply chain contexts also underlines the importance of decision rights: who decides what, and at what level. A coordination spectrum can range from independent (no shared decision rights), to consultative (joint exercise of rights), to synchronized decision-making (redesigning rights and responsibilities) (Simatupang and Sridharan, 2005).

4.1.4. Organizational Design in Supply chains

Organizational design in supply chains can be understood as the deliberate structuring of processes, roles and coordination mechanisms so that interdependent activities (forecasting, planning, procurement, production and logistics execution) are linked in a coherent end-to-end flow (Nakano, 2020). Nakano (2020) argues that it is often useful to describe the process first and the structure second, because organizational structures are "abstract" until they are anchored in the concrete sequence of planning and execution tasks that must be coordinated (Nakano, 2020).

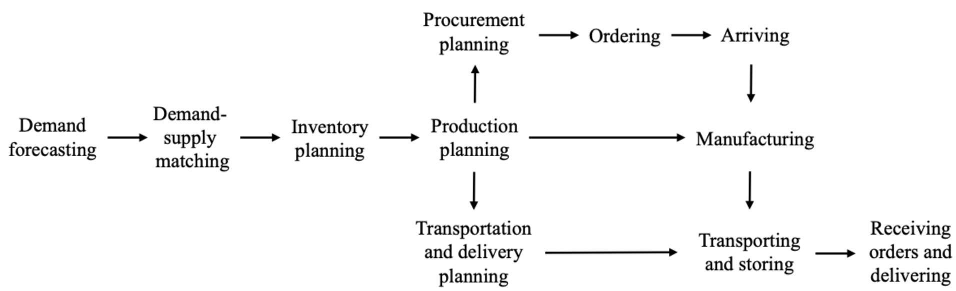

Figure 9: Internal supply chain processes (Nakano, 2020)

Within Nakano (2020)'s process view, "integration mechanisms" are defined as cross-functional activities and/or inter-organizational activities that link relevant business processes and eliminate duplicate or unnecessary process elements. These mechanisms are further conceptualized as interaction (meetings, calls, standard forms) and collaboration (shared goals, mutual understanding, shared resources, common vision), with collaboration often associated with stronger performance effects (Nakano, 2020).

From an organizational design perspective, this implies that alignment is achieved not only through communication intensity, but through the design of information sharing and decision coordination as explicit coordination devices (Nakano, 2020; Simatupang and Sridharan, 2005). Nakano (2020) further explains that internal coordination can follow different patterns - standardization, plan-based, and mutual adjustment - which are chosen depending on uncertainty and the need for feedback-based coordination (Nakano, 2020). Alignment theory also suggests that organizations need structures that can handle changing interdependencies, often by appointing process owners or integrators with enough authority to coordinate work across functions (Wong et al., 2012).

4.1.5. Digital Enablers for Alignment and Decision-Making

Digitization is often characterized as an enabler of supply chain alignment because it can improve visibility, efficiency, and the scalability of coordination across layers in the supply chain. Research on supply chain integration underline that IT solutions can enable larger volumes and higher complexity of information exchange, including real-time information on inventory, delivery status and production planning, and can today more often support alignment of forecasting and scheduling between different companies (Prajogo and Olhager, 2012).

However, it is important to consider that digitization must be governed to produce outcomes that result in improved supply chain alignment. Recent research on digital transformation frameworks argues that organizations need structured approaches that map technologies to business areas and define performance- or adoption indicators to track progress and impact (Fantozzi et al., 2025).

In addition to this, Dias and Ierapetritou (2017) argues that information required for critical decisions, and data is often collected and stored in different departments of supply chain organizations. This means that decision makers at different units frequently lack access to the full information set needed to make optimal supply chain decisions. Hence, advanced decision-support is constrained not only by model complexity, but also by data integration challenges. In their review, this fragmentation is presented as a key reason why integrated decision-making in supply chain organizations remains difficult in practice - despite having strong methodological and integrated solutions cross-functionally. This reinforces the role of governance in digital transformation. Structured frameworks and indicators can help organizations assess whether data is being effectively converted into operational improvements, e.g., through indicators such as data utilization, and whether technologies are meaningfully integrated into decision processes rather than remaining isolated "tool deployments" (Fantozzi et al., 2025).

4.2. Logistics Network Design

The second area of theory focuses on supply chain and logistics network design. This area of literature examines primarily how sourcing structures influence the design of logistics networks, including material flows and transportation structure. Central concepts include strategic network design and trade-offs between cost, quality and sustainability.

4.2.1. Network Design in Inbound Logistics: Definitions and decision variables

Inbound logistics network refers to the upstream supply network - the system of nodes (such as suppliers, consolidation sites, cross-dock centers, and manufacturing plants) and links (transportation lanes between those nodes) through which raw materials and components flow into a company's physical facilities. Inbound logistics covers all activities of "the management of materials from suppliers and vendors into production processes or storage facilities." (Inbound Logistics, n.d). Key design variables for an inbound network include the role and location of each node and the routing of material flows between nodes. For example, strategic network design decisions involve determining how many inbound consolidation centers or cross-docks to operate, where to locate them, which suppliers ship to which facilities, and what transportation modes to use on each lane (Chopra and Meindl, 2013). These structural choices define the constraints and opportunities for managing inbound flows.

Typical inbound network configurations can range from direct node-to-node shipments to different setups with several consolidation points. According to Hosseini et al. (2014) the following designs are most common in the automobile sector for inbound logistics networks:

- **Direct shipping:** Suppliers ship directly to the receiving plant or warehouse. This is most economical when shipments fill a full truckload (FTL) for a given origin-destination pair. Direct routes minimize handling and transit time but require sufficient volume; otherwise capacity is underutilized.

- **Cross-docking:** Shipments from multiple suppliers are routed through a cross-dock facility where they are unloaded, sorted or combined with other shipments bound for the same destination, and quickly reloaded - without long-term storage - onto outbound trucks. Cross-docking enables consolidation of less-than-truckload (LTL) orders into full loads, reducing total transport cost and inventory holding at the expense of an extra handling step. According to Hosseini et al. (2014), cross-docking eliminates activities associated with storage and produces faster flow and lower costs by avoiding warehousing.

- **Milk runs (supplier collections routes)**: A single vehicle picks up from multiple suppliers on a planned route and delivers the combined load to the plant. Milk runs are effective when many suppliers are located closer to each other and have LTL quantities. By consolidating pickups, the buyer avoids each supplier shipping small batches independently. This system has been widely adopted in industries like automotive manufacturing to support Just-In-Time (JIT) delivery, as it reduces total transport costs and inbound inventory by increasing shipment frequency for nearby suppliers.

- **Multi-stop truckload routes:** Similar to milk runs, a carrier might execute a multi-stop route either for pickups or deliveries to maximize trailer utilization. For inbound logistics, multi-stop pickup routes from clustered suppliers help achieve truckload economies of scale. These routes require careful routing and scheduling design to be effective.

- **Tailored or hybrid networks:** In practice, companies often use a mix of the above. High-volume suppliers or nearby suppliers might ship direct FTL, while low-volume or distant suppliers use consolidated hubs or milk runs. For example, a “tailored network” approach allows some flows to move direct and others via consolidation, whichever is most cost- or time-effective. The inbound network for a large manufacturer may involve several cross-dock centers for regional consolidation alongside direct routes for key suppliers.

When designing an inbound logistics network, a company also needs to consider decision variables like shipment frequencies, vehicle scheduling and consolidation rules e.g., when to hold a truck for consolidation versus when to dispatch it. These choices are often decided by operational factors such as lead time requirements, vehicle capacities and any sourcing constraints. In summary, an inbound network design specifies who ships what, from where, to where, how and how often, under given constraints. Because these design parameters determine how inbound material flow is organized, they have significant impact on cost, lead times and flexibility upstream in the supply chain (Chopra and Meindl, 2013).

4.2.2. Network Design Objectives and Structural Trade-offs

The purpose of designing supply chain networks is generally to optimize several core objectives. The primary objectives to optimize are cost, service level (responsiveness), sustainability, risk and resilience. Literature on this area emphasizes that decision-makers have to consider fundamental trade-offs between these objectives, and structural choices need to be made when designing these network configurations (Chopra and Meindl, 2013; Keramydas et al., 2017). Just as for decisions regarding SCM, it is important to consider that network design decisions create interdependent effects on cost, service and other outcomes across the entire logistics system (Chopra and Meindl, 2013).

A cost-efficiency versus responsiveness trade-off is central in network design (Chopra and Meindl, 2013). For example, locating more distribution centers, cross-docks or warehouses closer to customers (demand points) can reduce lead times (improving responsiveness), but maintaining additional facilities raises inventory and operating costs. As Chopra and Meindl (2013) observe, adding facilities beyond the cost-minimizing point will only be worthwhile if the gain in service (and revenue) outweighs the higher logistics cost (Chopra and Meindl, 2013). In other words, a network optimized purely for low cost (few, centralized facilities using economical transport modes) will tend to be less responsive (longer lead times), whereas a network configured for responsiveness (many decentralized nodes, express transportation options) will drive up costs. Referred to as positioning on the "cost-responsiveness efficient frontier" (see Figure 10) this trade-off means firms must decide how much responsiveness they are willing to pay for (Chopra and Meindl, 2013).

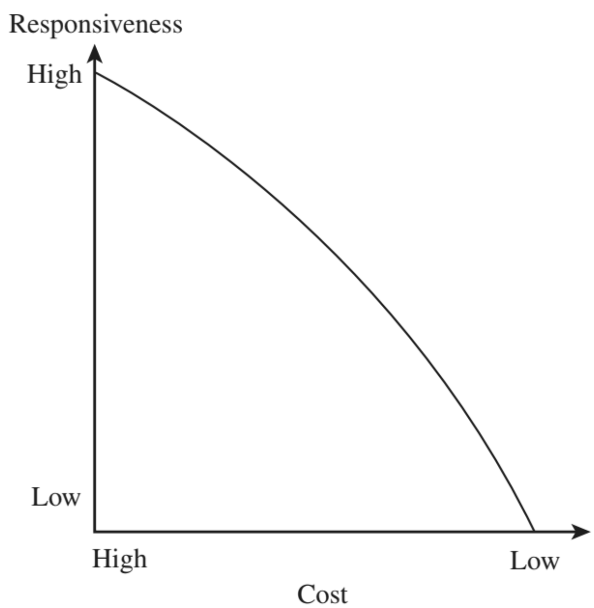

Figure 10: Cost-Responsiveness Efficient Frontier (Chopra and Meindl, 2013)

Inbound logistic network designs also cover the trade-off between the amount of consolidation and speed. Consolidation of flows favors economies of scale in transportation - resulting in lower unit transport costs - but often induces extra handling and waiting time (e.g., waiting to aggregate a full load) that can slow deliveries (Keramydas et al., 2017).

In contrast, direct shipping or node-to-node routes minimize transit time but may miss out on scale economies, increasing cost per unit shipped. For example, shipping LTL orders directly is faster but more expensive per unit, whereas consolidating them via cross-dock is cheaper but adds transit legs and coordination requirements. Thus, designs must balance speed versus efficiency. An inbound network heavily utilizing cross-docks and milk runs will have lower transport cost through higher asset utilization, but possibly longer and more variable lead times than a configuration of transportation flows that offers direct shipments (Keramydas et al., 2017).

Another choice regarding the design of the logistics network is the degree of centralization of facilities used in the supply chain. A centralized inbound network with fewer facilities simplifies coordination and exploits warehouse economies of scale, often yielding lower total inventory levels, but can result in longer distances to some destinations and potentially higher transport costs or lead times. Including more facilities in the logistic network can improve responsiveness and reliability to downstream nodes (shorter routes, easier scheduling, but comes at the cost of duplicated stocks and facilities. (Chopra and Meindl, 2013) illustrates this relationship in Figure 11 below. Their analysis shows that as the number of distribution facilities increases, total logistics cost first decreases (due to lower transport distance) but then rises once facility and inventory costs overwhelm transport savings.

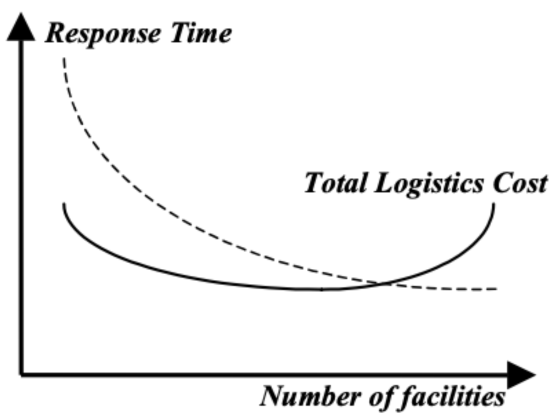

Figure 11: Chopra and Meindl (2013) visualization of total logistics cost as a function of number of facilities and response time.

Sustainability objectives add another dimension of trade-offs. Designing for minimal carbon footprint might involve using slower but greener transport modes e.g., rail or sea instead of faster air freight or sourcing from closer suppliers to cut emissions, which can conflict with cost objectives. Keramydas et al. (2017)'s study evaluated the trade-off between cost and emissions in logistic network design. They attempted to optimize logistics networks for both low cost and low CO_2 emissions and concluded that it requires compromises, such as slightly longer delivery routes or higher inventory to allow more energy-efficient transport modes (Keramydas et al., 2017). In some cases, investments in consolidation both save cost and reduce emissions per unit, but in others, the lowest-carbon solution may raise short-term costs. Researchers note that most network design models still prioritize cost, but there is growing inclusion of environmental criteria alongside cost and service (Keramydas et al., 2017).

Finally, risk and robustness are key objectives influencing modern network design. A highly cost-optimized network e.g., single sourcing with centralized routes can be vulnerable to disruptions (natural disasters, port strikes, financial disruptions etc.). Thus, firms consider trade-offs between efficiency and resilience. Building in redundancy or flexibility - e.g., multiple supplier sources, alternate distribution routes, extra capacity - can mitigate risk but usually incurs additional cost. The structural complexity of a supply network also affects risk propagation (Lu and Shang, 2017). There is evidence that a supply base structure can have non-linear effects on performance: some complexity (e.g., multi-sourcing) may improve resilience up to a point, but excessive complexity can hurt cost and reliability (Lu and Shang, 2017). Therefore, network designers face decisions like whether to centralize for efficiency or decentralize for risk mitigation, and how to quantify the cost of potential disruptions versus the cost of preventive redundancy. Analytic models attempt to capture these risk trade-offs (Klibi and Martel, 2011).

4.2.3. Supplier Base Effects on Network Flows

The configuration of a company's supplier base - including the geographic distribution of suppliers and the volume/mix of goods they provide - has a profound impact on the performance and design of a logistics network (Norrman and Olhager, 2023). First of all, supplier geography directly affects the inbound transportation lanes, distances and feasible transport modes (Chopra and Meindl, 2013; Kawasaki et al., 2015). If a company sources globally, from low-cost countries, the inbound network will include long transport lanes, and likely involve ocean, air freight and multiple handling points. This typically results in longer lead times, higher transport costs and greater exposure to disruption risks (NetSuite, 2025). In contrast, a more localized or regional supplier footprint shortens supply chain distances, resulting in smaller transit times and reduced distances. This logically enables more frequent deliveries and easier coordination. As discussed in the background chapter, many global manufacturers today are reconsidering overly globalized supply chain networks (Baldwin and Freeman, 2022; Boston Consulting Group, 2021).

A supplier base characterized by local sourcing, offering more reliability and responsiveness, can potentially come at the expense of higher unit costs from more local sources (NetSuite, 2025). A recent study by PwC found that moderate localization of sourcing often yields notable improvements in lead time and risk reduction, even if production costs per unit increases (Chopra et al., 2004; PwC, 2024). Therefore, it is of great importance to weigh the cost savings of global sourcing against the increased transport distances in the logistics network.

Secondly, supplier volume and the product mix changes will alter the pattern of flows in the inbound logistics network. Changes like these affect the density of the transported volumes and the efficiency of consolidation of goods. For example, if the inbound order volumes from a supplier (or a region) increase, it becomes easier to consolidate shipments into FTL's on that specific lane, which in turn improves overall transport load efficiency (Chopra and Meindl, 2013; Fleischmann et al., 1998). In contrast, if volumes per supplier drop, or become more fragmented across many suppliers, direct TL shipments may no longer be possible (Fleischmann et al., 1998). Therefore, the logistics network must adapt by using LTL shipments or consolidating loads for multiple suppliers by milk-runs. For example, if a plant previously received a full truck weekly from supplier A, but now that volume is split among three smaller suppliers, a milk run to pick up from all three suppliers on route needs to be considered as a substitute (Hosseini et al., 2014). Changes in the product mix can also have significant effects on the logistics network. A highly modular product mix can offers significant advantages by enabling multiple end-product configurations, but they can also introduce severe product complexity at the individual component level, for example connected to forecasting demand for specific components (Norrman and Olhager, 2023).

4.2.4. Key Performance Indicators for Logistics Network Evaluation

When evaluating supply chain network design scenarios, performance must be assessed across multiple dimensions (Fleischmann et al., 1998; Persson and Olhager, 2002). Measurement is an essential component of the management process since it is necessary to verify whether implemented decisions and actions have actually achieved their intended goals (Fleischmann et al., 1998). Within the framework of continuous quality improvement, this corresponds to the ”Check” phase of the PDCA (Plan-Do-Check-Act) cycle (Fleischmann et al., 1998). Without proper measurement and evaluation, an organization lacks the necessary feedback loops to determine if its operational solutions and changes genuinely cause improvements (Fleischmann et al., 1998).

To facilitate continuous improvements and evaluate the impact of decisions, organizations must utilize robust performance measurement systems (Wong et al., 2012). A properly designed performance measurement system helps decision-making by providing timely feedback that indicates how well the supply chain has performed, where it currently stands and what targets it need to reach (Wong et al., 2012). Ultimately, these measurement systems are responsible for maintaining alignment and coordination across the organization, as they motivate staff and ensure that operational processes remain aligned with broader strategic objectives (Wong et al., 2012). Performance measurements fundamentally shape organizational behavior, built on the idea that ”what gets measured, gets managed” (Christopher, 2016). When management fails to provide clear KPIs or establish explicit targets, it deprives the different functions of the communication mechanisms needed to establish accountability and encourage cross-functional teamwork (Christopher, 2016). Consequently, without defined KPIs, operational functions are unable to evaluate what is actually expected of them or validate whether their decisions are beneficial to the overall system (Christopher, 2016; Wong et al., 2012).

Logistic Network Key Performance Indicators

Establishing appropriate KPIs are therefore crucial to determine the efficiency and effectiveness of modeled logistics networks and/or to compare alternative systems (van der Zee and van der Vorst, 2005; Lundin and Norrman, 2010). Persson and Olhager (2002) identify total cost, lead time and quality as KPIs, arguing that these metrics capture both resource utilization and customer value in supply chain operations. Beamon (1998) explains that when designing and evaluating supply chain set-ups, the KPIs can be divided into quantitative and qualitative categories. Within the quantitative measures, cost minimization, i.e. minimization of total logistics cost, is the most widely used objective and can be applied for particular business units or stages of a supply chain (Beamon, 1998). In performance measurement of supply chain modeling and logistics network design, total costs are assumed to be the sum of the average inventory cost, transportation, and other facility costs for a supply chain network (Beamon, 1998; Chopra and Meindl, 2013). Other KPIs that are useful to include in logistics network evaluation are customer satisfaction/service levels, flexibility and lead time minimization (Beamon, 1998).

In addition to traditional KPIs such as logistic costs and lead time, environmental KPIs have gained prominence as supply chains are increasingly evaluated on sustainability. Building on this foundation, Kawasaki et al. (2015) proposes a multi-objective KPI framework for sustainable logistic network design by incorporating logistics cost, CO_2 emissions and lead times as key indicators (Kawasaki et al., 2015). Emissions are calculated based on transport distance, mode and volume, enabling comparison between design alternatives (Fleischmann et al., 1998; Keramydas et al., 2017). It has been shown that only including traditional cost-objectives in logistics network design, lead to environmental suboptimal solutions (Garcia and You, 2015). The most typical sustainability-related KPIs include total CO_2 emissions, and which are calculated based on transport mode and distance and energy intensity per shipment (Eskandarpour et al., 2015; Kawasaki et al., 2015).

Keramydas et al. (2017) further reinforce the importance of sustainability-related KPIs by implementing a simulation-based optimization framework that jointly considers logistics costs and CO_2 emissions. Their case study of a multi-echelon network illustrates how environmental KPIs - specifically CO_2 emissions from transportation and facility operations - can be calculated for each route and process step using transport mode, shipment size and distance as input factors (Keramydas et al., 2017). Their results show that even small shifts in network configuration (e.g., adding regional distribution centers) can lead to measurable differences in emissions and costs. Importantly, they highlight that sustainable network configurations often involve trade-offs in service level and logistic cost, requiring multi-objective evaluation to achieve balance between economic and environmental performance (Keramydas et al., 2017).

Beyond traditional cost and environmental KPIs, a comprehensive evaluation of logistic network design should also look to incorporate robustness and resilience to ensure sustainable value creation (Klibi and Martel, 2011). Traditional supply chain and logistic network models often fail when implemented in the real world since they often don't address uncertainties and imperfect information (Bellamy and Basole, 2013; Simatupang and Sridharan, 2005). To address this, the performance of logistic networks should also be assessed based on the network's ability to manage both "business-as-usual" randomness such as demand fluctuations, and major disruptions such as natural disasters or strikes (Klibi and Martel, 2011). Klibi and Martel (2011) identifies three key strategic dimensions for evaluating logistics network performance under uncertainty. The first is robustness and is characterized by the ability of a logistics network to remain effective and provide sustainable value across all possible future scenarios. The second KPI is responsiveness and is defined by the network's ability to respond positively to short-term variations in business conditions. Thirdly, resilience is an important KPI measure, and is the strategic capability of a network to either bypass potential threats or bounce back efficiently when failures occur, supported by pre-allocated resources and a flexible organizational structure.

4.3. Simulation-Based Decision Support

In their book, Laguna and Marklund (2019) discuss business processes and the definition of a process as the specification of the transformation of inputs to outputs. Furthermore, they argue that as a result of this, "any organizational entity or business can be characterized as a process or a network of processes." Laguna and Marklund (2019) further goes on to split processes into three categories:

1. Individual processes - processes carried out by separate individuals
2. Vertical or functional processes - processes that are contained within a certain functional unit or department
3. Horizontal or cross-functional processes - processes which cut across several functional units or across different companies

There naturally exists a hierarchical relationship between these different process categories as cross-functional processes can be broken down into several functional processes which in turn can be broken down into several individual processes. Furthermore, each process can also be split into several activities which themselves are composed of multiple tasks (Laguna and Marklund, 2019). Hence, processes involving additional functional units or companies become exponentially more complex. Cross-functional processes are deemed to often offer high improvement potential, mainly due to their difficulty of coordinating and that they often aren't optimally organized (Laguna and Marklund, 2019). Furthermore, increased supply chain complexity also increases the risk of supply chain disruptions (Saisridhar et al., 2024; Correa-Martinez and Seck, 2023), meaning that complex, cross-functional supply chain processes are the hardest processes to model and the most prone to disruptions.

Companies often struggle in optimizing cross-functional processes as they generally are too complex and interdependent for static optimization models and rule-based planning to be able to accurately model reality due to their dynamic and transient characteristics (Saisridhar et al., 2024). When companies become unable to reliably model their processes, optimizing them becomes an impossible task (Laguna and Marklund, 2019; López-Pintado et al., 2024). Moreover, assessing the impact of supply chain disruptions through analytical models is also very hard - maybe even not feasible (Dohmen et al., 2022). Dohmen et al. (2022) argue that the reason for this is that modeling the reactive techniques employed by firms that experience process disruptions in order to regain their performance, is hard as firms often make multiple changes to their operations simultaneously.

Many firms facing challenges in complex supply chain configurations, business process improvements and predicting impacts of uncertain events, use simulation in their decision making processes (Liotta, 2012). This is due to the inherent flexibility in the simulation models which are able to account for the dynamic properties of supply chain processes unlike static models (Liotta, 2012; van der Zee and van der Vorst, 2005).

4.3.1. Business Processes

The structure for a business process can be split into five distinct components: the inputs and outputs, the flow units, the network of activities and buffers, the resources and the information structure (Laguna and Marklund, 2019).

Inputs and Outputs

Inputs and outputs are the data streams which enter and exit the process. In order to understand what the model's inputs and outputs are, the model's boundaries need to be identified, i.e. where the process begins and ends (Laguna and Marklund, 2019). It's important to note that in real business processes, the inputs and outputs can be tangible. For example, an input could be the gas that fills up a truck traveling to a supplier site and an output could be the amount of emissions from the truck during the trip.

Flow Units

Laguna and Marklund (2019) define a flow unit as a "transient entity", that moves throughout - and is processed in - the model before exiting as an output. Depending on the context, flow units can be altered in different ways before exiting the model. A flow unit could for example be a component that is combined with other flow units and then exit the model together as a finished product. van der Zee and van der Vorst (2005) support the notion of flow units being entities that move throughout the simulation model, although they notate them as "flow items" rather than flow units.

Network Activities and Buffers

Activities and buffers are the components of a process that the flow units pass through to be transformed from outputs to inputs. Laguna and Marklund (2019) define activities as "micro-processes" which consist of sub-tasks that are performed on the flow unit. This definition necessitates the maker of the model to make a sound judgment on the level of detail in which to break down activities into sub-processes, as the hierarchical structure could theoretically be broken down into an infinite number of sub-processes. There is also a tradeoff between activity- and process complexity as the process becomes structurally less complex the more complex and encompassing each activity becomes (Laguna and Marklund, 2019). See Figure 12 for a visual representation of the complexity tradeoff between individual activity complexity and overall process complexity.

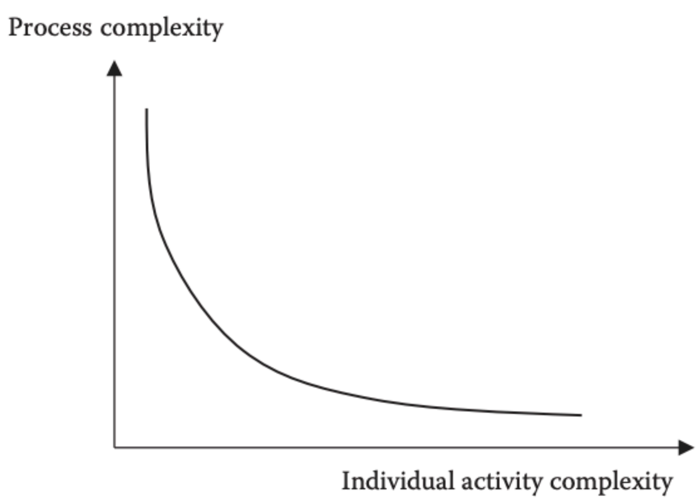

Figure 12: Process complexity versus individual activity complexity (Laguna and Marklund, 2019).

Most processes also include buffers between activities which can store flow units. Laguna and Marklund (2019) don't define buffers, but give examples of what buffers could be which include queues, inventories and waiting rooms. A common goal in business process design is to minimize the amount of time that flow units spend in buffers in order to increase the flow rate of the overall process (Laguna and Marklund, 2019).

Another common goal in business process design is to eliminate non-value adding activities in processes in order to achieve a more efficient process (Laguna and Marklund, 2019). Laguna and Marklund (2019) offer two possible classification structures of activities which both differentiate activities between value adding and non-value adding activities (see Figure 13). Laguna and Marklund (2019) define non-value-adding activities as activities which customers would not be willing to pay for. The main difference between the two classification structures is the distinction of business-value-adding activities and non-value-adding activities. The rationale behind this distinction is that while customers may not be willing to pay for activities such as control, these are still seen as essential to conducting business and should therefore be separated from activities which are purely non-value-adding for both the customers and the business. This reasoning ties back to the goal of minimizing or eliminating non-value-adding activities; while elimination of policy compliance would be problematic, elimination of reworks would be a theoretically attainable and positive outcome.

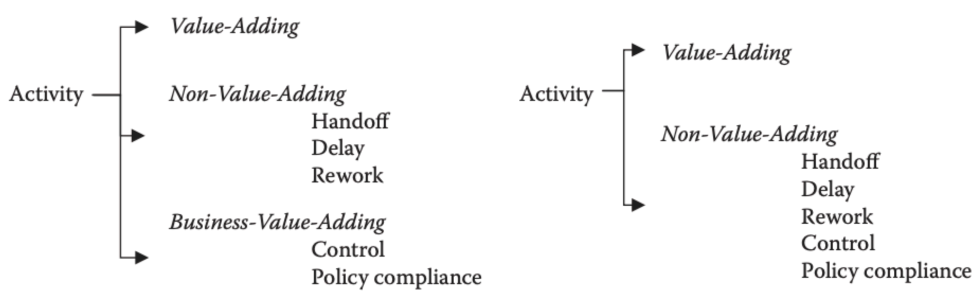

Figure 13: Classification structures of activities (Laguna and Marklund, 2019).

Resources

Laguna and Marklund (2019) define resources as "assets that are necessary to perform activities within a process." They provide examples of resources such as the machinery in a job shop, the aircraft for an airline and the faculty at an educational institution. Furthermore, resources are often classified as either capital assets such as machinery, equipment or systems, or as labor such as the organization's employees (Laguna and Marklund, 2019). What separates resources from inputs are that resources are not consumed in the process, but rather serve as catalysts for the process. An example of this distinction would be that of a truck and its fuel. Since the fuel would be consumed, it would be classified as an input while the truck would be a resource since it is reusable.

Information Structures

The final element of a business process is the information structure. The information structure describes what information is needed to perform the process as well as the information that is available (Laguna and Marklund, 2019). To exemplify, let us imagine a process where a truck transports goods from one point to another. The information structure would for example dictate how much fuel the truck would consume, how much loading capacity it has, the properties of the goods to be transported, such as weight and volume, among other needed characteristics to be able to model the performance of operational policies.

Simulation of Business Processes

Based on the definitions of the elements, hierarchies and architecture of the business process, Laguna and Marklund (2019) define the overall business process as "a network of connected activities and buffers with well-defined boundaries and precedence relationships, which use resources to transform inputs into outputs for the purpose of satisfying customer requirements" (see Figure 14).

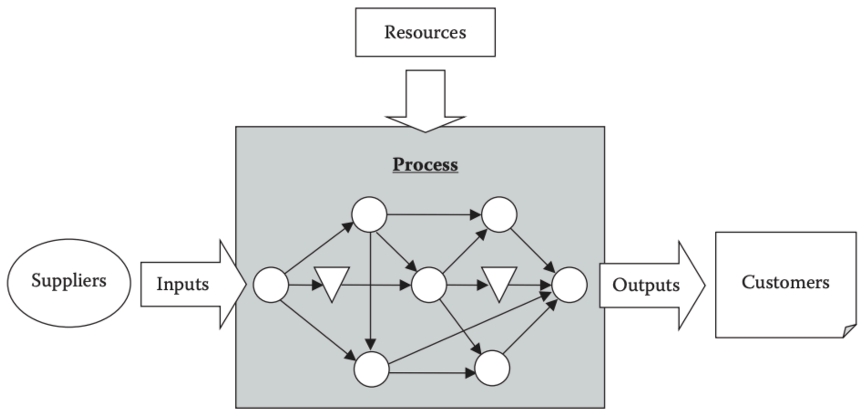

Figure 14: The business process (Laguna and Marklund, 2019).

For the purpose of modeling and testing proposed business process designs, Chase et al. (1998) advocate the use of computer simulation as a structured decision-support tool. Laguna and Marklund (2019) argue that while pilot implementations can be used to test redesigned processes, such approaches are often costly, time-consuming, and disruptive to ongoing operations. Simulations offer a more flexible and resource-efficient alternative, enabling process owners to evaluate alternative configurations before implementation. By allowing multiple design options and parameter adjustments to be tested in a controlled environment, simulation supports informed decision-making in complex processes.

According to Laguna and Marklund (2019), simulation means "to mimic reality in some way". In a business process context, simulation software is used to create a computer model that mimics the behavior of a real-word process. The process is presented as a dynamic system consisting of interconnected activities, buffers, resources and flow units (Laguna and Marklund, 2019). Unlike static analytical models, simulation models are typically dynamic, stochastic and discrete (Keramydas et al., 2017). This means that simulation models explicitly incorporate time, variability and real-time changes. Simulations can also be continuous rather than discrete, if the simulated entities follow continuous functions (Saisridhar et al., 2024). Examples of processes where this would be more applicable could for example be a model simulating the altitude of an airplane or the pressure in an oil pipeline. Here, the simulated values would need to be modeled with differential equations as the altitude for example couldn't reasonably jump 1000m of altitude or the pressure in an oil pipe couldn't be halved in an instant. However, if the arrival of a truck would be modeled, there would be one discrete moment where the truck arrives and that precise moment is the interesting aspect.

The simulation of business processes generally consists of four main steps: building a model, running it, analyzing the performance outcomes and evaluating alternative scenarios (Laguna and Marklund, 2019). Furthermore, the actual development of a simulation model requires a structured workflow that begins with defining clear objectives and mapping of the system's logic (Laguna and Marklund, 2019). This is followed by technical assembly of the model using block diagrams and specific parameters. The most critical phase involves rigorous verification and validation to ensure accuracy, ultimately allowing for data collection and analysis to drive informed decision-making (Laguna and Marklund, 2019).

It is important to note that simulation in itself does not inherently optimize a process. Rather, it evaluates the performance implications of specified input configurations (López-Pintado et al., 2024). The simulation model can therefore be used to generate so-called "what-if" scenarios, which allow decision-makers to assess systematic consequences of design changes without disturbing the real system (López-Pintado et al., 2024; Laguna and Marklund, 2019). However, simulation can be combined with optimization techniques in so-called simulation-based optimization models. In these models, the information structure changes during the simulation, and ultimately guides the process design to its optimal structure (Laguna and Marklund, 2019). Furthermore there are multiple types of decision-supporting information that simulation models could output. Because of this, it is imperative that the simulation model is configured to output the relevant information in order to signal whether or not changes should be made or if the tested process design is performing in accordance with overall business goals ((Laguna and Marklund, 2019).

Given that business processes - particularly cross-functional supply chain processes - are characterized by complexity, interdependencies, and uncertainty, different simulation approaches may be more or less appropriate depending on the modeling objective (López-Pintado et al., 2024). The following section therefore reviews the main types of simulation methods used in industrial contexts and discusses their applicability in complex supply chain environments.

4.3.2. Types of Simulation Used in Industrial Contexts

In industrial supply chain management, simulation is commonly applied as a tool to support decision-making processes and to explore "what-if" questions in complex and dynamic systems where analytical methods may be restrictive (Tako and Robinson, 2012; Wang and Moon, 2013; López-Pintado et al., 2024). As previously discussed, a central question is the selection of an appropriate simulation approach. The approach should reflect the modeling objective and the perspective taken on the system (Saisridhar et al., 2024). In supply chain literature and industry contexts, three simulation paradigms dominate: discrete-event simulation (DES), system dynamics (SD), and agent-based simulation (ABS) (Saisridhar et al., 2024). As these three approaches have inherent strengths and weaknesses, there are also possibilities of combining the different approaches in the same model to offer more exhaustive modeling capabilities (Tako and Robinson, 2012).

4.3.2.1. Discrete-Event Simulation

Discrete-event simulation (DES) is the most common way to represent business processes as computer-based models that are dynamic, stochastic and discrete. In simple terms, DES describes how a system with specific flow units (e.g., shipments, orders) evolves over time. Rather than modeling the system continuously, a DES model tracks the system's so-called state variables. Classical state variables are often exemplified by queue lengths, work-in-process and resources available, and in DES models these variables are only updated when an event occurs. Typical events include arrivals, service completions, breakdowns or routing decisions (Laguna and Marklund, 2019).

A defining characteristic of DES is hence that it only focuses on the specific points in time when these events happen. Between two consecutive events, the model assumes that the system remains unchanged. This enables strong time compression, since the simulation can "jump" directly from one event to the next instead of computing periods where nothing changes. As a result, a computer can simulate an extensive period of real-world time by processing a large number of events in a relatively short time (Laguna and Marklund, 2019).

In supply chain management, DES is a versatile tool used to make better decisions. It is commonly applied for decisions regarding the design of logistics networks, managing inventory, schedule production, and selecting the right suppliers. Research by Tako and Robinson (2012) highlights that DES is particularly effective for optimizing distribution, transportation and restocking rules. It is particularly useful when a problem is complex, specifically when you need to see exactly how detailed processes - such as physical flows and bottlenecks - will affect overall performance.

4.3.2.2. System Dynamics

System Dynamics (DS) is a simulation approach designed to model and analyze the behavior of complex systems over time, particularly where feedback loops, accumulations and time delays play a central role. Rather than modeling individual events or process steps, as in DES, SD represents systems at an aggregated level through stocks, flows, and feedback structures that capture how variables influence on another dynamically (Saisridhar et al., 2024).

A defining characteristic of System Dynamics (SD) is its focus on relationships and feedback loops. In a supply chain context, these mechanisms can be illustrated by how a company adjusts its orders based on fluctuating inventory levels or shifts in perceived customer demand. These feedback effects can create nonlinear system behavior over time, such as oscillations or amplification scenarios (Saisridhar et al., 2024). Tako and Robinson (2012) highlight that SD has been widely used in supply chain research to model such dynamics, particularly phenomena like the bullwhip effect, where small demand variations amplify upstream due to feedback and delay structures.

Unlike DES, which typically includes operational processes in detail, SD models are generally more aggregated and policy-oriented. They are specifically useful when the modeling objective is to explore strategic or structural policy effects rather than detailed operational performance. For example, SD can help analyze how changes in replenishment rules, information-sharing policies, safety-stock parameters or lead-time assumptions influence supply chain systems over longer time horizons (Saisridhar et al., 2024).

4.3.2.3. Agent-Based Simulation

Agent-Based Simulation (ABS) models a supply chain as a set of autonomous, heterogeneous actors called "agents" that make decisions locally and interact with each other and with their environment (Wang and Moon, 2013), such that system-level behavior emerges bottom-up from many micro-level behaviors (Lewe et al., 2014). This makes ABS specifically useful when then the modeling objective depends on decentralized decision-making and interaction effects (Garcia and You, 2015). Clausen et al. (2019) emphasizes in their research that classic DES simulation can reach limits when modeling individual interacting system components in complex socio-technical logistics systems. In these situations, ABS offers greater flexibility and adaptability by explicitly representing interacting agents and their environment. Furthermore, Clausen et al. (2019) also note that agents can be defined with decision rules ranging from simple "if-then" logic to more advanced algorithms. They also highlight that the need for detailed knowledge of agent behavior and interactions can be a major limitation, meaning that ABS is powerful, but data knowledge is important (Clausen et al., 2019). A practical illustration of ABS is provided by Helo and Rouzafzoon (2023)'s agent-based logistics optimization model, where they have used agents, corresponding to facilities, trucks and orders. These agents act autonomously and interact with each other to model pickup- and delivery operations under uncertainty, production operational KPIs and enabling scenario analysis - for example facility location and fleet sizing decisions (Helo and Rouzafzoon, 2023).

4.3.2.4. Multi-Method Models

Combining multiple simulation methods within the same model is often used to move beyond siloed system representations. It enables the capture of interaction effects across upstream and downstream functions, while also incorporating a strategic dimension into otherwise operational models (Tako and Robinson, 2012). As the capabilities of a multi-method model increase compared to a single-method model, the possibilities of use-cases for combined models vary. Examples include, Wang and Moon (2013), who employed a combined ABS and SD to develop a simulation model for assessing innovation deployment strategies, Chahal et al. (2013) developed a framework for using SD and DES in a combined model to be applied to the healthcare domain by modeling behavioral effects on operational performance and Alvanchi et al. (2011) also combined SD and DES methods to develop a framework for modeling construction systems. All of these aforementioned examples utilize inherent characteristics of the respective simulation methods to achieve complementing insights necessary for modeling complex, interdependent systems. Notably, multiple authors press the fact that there are few multi-method simulation tools which have been implemented in real life industry contexts (Alvanchi et al., 2011; Chahal et al., 2013; Wang and Moon, 2013).

4.3.3. Organizational and Technical Prerequisites for Simulation-Based Decision Support

The lack of organizational competence and the substantial effort required are well-known barriers to simulation adoption. Implementing simulation tools requires specialized skills and significant, dedicated effort for problem definition, data collection, and model validation (Laguna and Marklund, 2019). Laguna and Marklund (2019) further emphasize that experienced analysts who understand both the science of modeling and the art of abstracting reality are the most critical component for success.

In addition to the organizational requirements, the usefulness of a simulation model is highly dependent on the quality of the input data and how well it captures real life performance and the information acquisition in the process of model building often takes up to one third of the total project effort (Kuhnt and Wenzel, 2010). Main challenges include non-existence of data, lack of access to data sources and low-quality of collected data or corrupted data. It is also important to cater the data collection to the chosen modeling method (Kuhnt and Wenzel, 2010). In fact, experienced simulation analysts often consider data management to be the most challenging and dangerous aspect of simulation projects and warns about missing the warning signs of data problems (Laguna and Marklund, 2019). Organizations frequently struggle with either having insufficient data or having too much data trapped in large databases where extraction and formatting are non-trivial tasks (Laguna and Marklund, 2019).

Furthermore, emphasis needs to be placed on what outputs the model should generate in order to keep the complexity of the model to a minimum (Laguna and Marklund, 2019). Hence, in order to efficiently create and use a simulation model, informational prerequisites need to be established in early stages of the modeling development process. Kuhnt and Wenzel (2010) propose a seven-step procedure model for information and data acquisition which can be found in Figure 15.

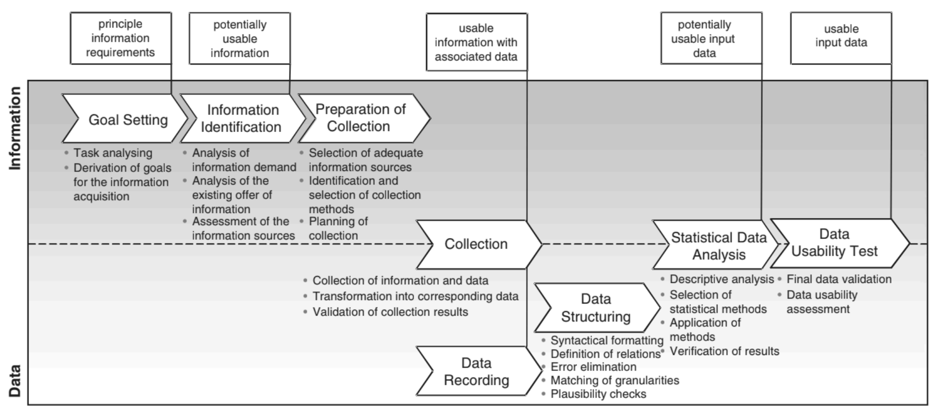

Figure 15: Procedure model for information acquisition (Kuhnt and Wenzel, 2010).

Kuhnt and Wenzel (2010)'s procedure model's first step consists of clearly defining the simulation's goals and from that, deriving clear information requirements. Defining the goal of a simulation project establishes the foundational step for the entire project. The organization must then be capable of performing structured "Information Identification", which involves specifying the needed level of detail of the information, i.e., the data granularity. The next step consists of performing a Gap Analysis by assessing available sources against these requirements. Thereafter, the model involves planning and execution steps, i.e. selecting relevant information sources (e.g., experts, documents) and then choosing appropriate and validated "Collection" methods based on a cost-benefit calculation. Furthermore, the procedure includes assessing the technical capacity for "Data Structuring" i.e. the ability to process raw data, eliminate inconsistencies, and transform data into a usable format for the simulation model. Finally, the model suggests a serious commitment to continuous Verification and Validation (V&V) throughout the process, culminating in the "Data Usability Test", which explicitly checks the data credibility, -correctness and technical usability as input for the simulation model (Kuhnt and Wenzel, 2010). Laguna and Marklund (2019) also propose a step-by-step procedure to developing simulation models which covers the entire development process end-to-end. Their ten-step procedure is explained shortly in Table 9.

Table 9: Ten-step procedure for developing simulation models (Laguna and Marklund, 2019).

Step	**Description**
1. Defining the problem	Define exactly the problem that needs to be solved, including defining the scope and level of detail. Questions should be defined which the model will answer and they should be split into “key” and “desirable” questions.
2. Understanding the process	Gain a thorough understanding of the process to be modeled. Identify vital components of the process and include them in the model.
3. Determining goals and objectives	Once the process is sufficiently understood, the simulation project is planned. Determine what scenario(s) should be simulated and what evaluation criteria will be used to analyze model results.
4. Obtaining support from management	Obtain clear support from management and ensure that results will be used and relevant to overarching business goals. Align with management to ensure that model capabilities and limitations are understood.
5. Choosing simulation software	Evaluate available software options for simulation and choose the one which best fits your needs. It is recommended to seek the opinion of consultants who have experience of using multiple vendors and companies with similar applications.
6. Determining data requirements and availability	Establish your data sources and evaluate the suitability of available data. Plan for data transformation and highlight gaps needing to be filled.
7. Developing assumptions about the problem	Develop assumptions for areas which lack sufficient data and where collection of data is impossible or infeasible. State clearly which assumptions are made and why they are necessary and reasonable.
8. Determining desired outputs	Determine what information that the simulation model should generate and how that information can be used for decision-making. Make sure that desired outputs match the chosen simulation method.

Step	Description
9. Building the simulation model	Decide whether the simulation model should be built internally or externally. If the company lacks previous experience in simulation, there could be a strong case for utilizing external expertise. A combination may also be used where consultants support initial development.
10. Project kickoff	Host a formal kickoff meeting highlighting milestones, showcasing results and discussing them. Give stakeholders the opportunity to ask questions, voice concerns and align on next actions.

4.3.3.1. Required Information

Because data gathering often takes a long time, it is critical to establish the data requirements as early as possible in the project (Kuhnt and Wenzel, 2010). There are several types of data typically used in simulation models. They include time-based data such as arrival times, processing durations, transport times, lead times among others. Other relevant data types are fractions which include failure rates, reworking ratios, categorical splits of customer types or available equipment types and so forth (Laguna and Marklund, 2019). Furthermore, sample sizes need to be sufficiently large to ensure statistical robustness, and data types need to be up to date, relevant to the process and quantitative and generated or presented in the right format. Data sources include direct observations, historical data and automated data (Kuhnt and Wenzel, 2010). When dealing with automated data, it is also important to ensure that the process of how the data is processed and presented is understood to eliminate the risk of drawing faulty inference from it. Laguna and Marklund (2019) emphasize the importance of treating employee testimonies with skepticism as humans tend to fall prey to biases such as recency bias and understating extreme situations. Furthermore, when data is corrupted, faulty or non-existent, Laguna and Marklund (2019) mention that processes which are truly random often can be modeled via the exponential distribution which does a good job of capturing underlying uncertainty.

4.3.3.2. Input Analysis

In order to have a useful simulation model that supports sound decision making, analysis of both the data that feeds the model as well as the data that the model outputs, is required (Laguna and Marklund, 2019; van der Zee and van der Vorst, 2005). This is because the model needs to be fed data in a certain format as previously mentioned, and because the output from the model will not be actionable or easily comprehensible unless properly analyzed.

Business processes are mostly stochastic due to them usually containing factors such as processing times, arrival rates, transport times, etc., making statistics a necessity for input analysis (Höst et al., 2006). Utilizing statistics and statistical distributions allows the model to mimic the real systems and processes without overly simplifying them and a big part of that is the randomness and shocks that affect processes and systems (Garcia and You, 2015). Let's explain this with an example of a truck manufacturer's assembly line where assemblers build components by adding piece by piece in a sequence. If one of the assemblers is sick one day, that will cause problems for the assembly process and could lead to the process stopping or being delayed. This is an example of a random shock which would be hard to capture accurately in a deterministic model. This problem amplifies as you include more and more assemblers in the process which all have their independent risks of being sick and the complexity increases if the risk of an assembler becoming sick is increased if their coworkers are sick as well. Now, there may not be a large disruption to the process if one assembler becomes sick - maybe their workload could be absorbed by their coworkers. But there will be rare cases where larger parts of the workforce become sick at the same time and then the system performance could be drastically affected. By using stochastic processes, the model is able to capture the effects of small statistical outliers and how these affect the performance of the system (Alvanchi et al., 2011).

By looking at historical data and analyzing it, processes' inherent characteristics can be modeled through fitting distributions that exhibit similar randomness to the real processes' characteristics (López-Pintado et al., 2024). Worth noting here is that different processes will exhibit different characteristics. For example, interarrival times may be better approximated by an exponential distribution while processing times for an industrial machine might follow a normal distribution (Laguna and Marklund, 2019). However, using historical data to mimic the randomness of a real process has several limitations. Field data is expensive to obtain, meaning that data quantity is often limited (Laguna and Marklund, 2019). Furthermore, field data is also not available for processes which aren't in operation, meaning that this data type can't be used for modeling new processes accurately. Field data for similar, previous processes can be used indicatively for new processes, but this limits inference and the ability to draw conclusions (Robinson, 2013). The lack of several scenarios represented in field data also limits the model's ability to accurately be able to support sensitivity analysis and inform the analyst of effects that variance in conditions have on process performance (Laguna and Marklund, 2019). Despite these shortcomings, field data is exceptional for validation of simulation models (Laguna and Marklund, 2019). Validation of the model is done by checking that the model performs the same way that the real processes does when both processes are subject to the same conditions. If the model performs differently, then that is a clear sign that the model isn't accurately mimicking the real process and that changes to the model are needed.

With the limitations of field data's ability to predict future behavior, simulation models are usually built on artificially generated data (Laguna and Marklund, 2019). The goal is to generate artificial data in the same pattern that the real system exhibits. Laguna and Marklund (2019), present a three step procedure to create representative artificial data. Firstly, a sufficient amount of field data needs to be collected in order for the sample to effectively represent the population and the collection must follow the rules of sampling that ensure statistical validity. Secondly, statistical analysis of the field data needs to be performed to find the underlying probability distribution that the population follows. This entails identifying the probability distribution function as well as the parameters of said function. Lastly, a random number generator needs to be used to generate random numbers from the probability distribution established in step two. Furthermore, Laguna and Marklund (2019) argue that step two in this process - the process of determining the underlying probability distribution - can itself be split into three phases. The first phase serves to identify the distribution family. This phase is quite informal and can for example be done by plotting histograms of the field data and visually comparing these to well-known or hypothesized probability distribution functions plotted in the same graph (Höst et al., 2006). Once the first phase is concluded and a probable distribution family is identified, phase two consists of estimating the distribution parameters from the field data. For example, if the identified distribution family is the normal distribution, the mean and standard deviation of the sample could be used. Once this phase is concluded, a hypothesis of the probability distribution has been established. Lastly in the final phase, tests are performed to conclude whether the null hypothesis can be rejected. If the hypothesis is rejected. Phase 1 is restarted and the process repeats until a hypothesis that cannot be rejected is found.

If the analyst ultimately cannot find a well-known distribution family that isn't rejected, the empirical probability distribution may be used (Laguna and Marklund, 2019). Examples of the well-known distribution families include the uniform, triangular, normal, exponential, binomial, Poisson, Erlang, Weibull, beta and gamma distributions (Laguna and Marklund, 2019). It is worth noting that the null hypothesis that is tested, is whether the given amount of data points are independently drawn from the theoretical distribution. If the null hypothesis is rejected, the analyst can conclude that the theoretical distribution is not a good fit for the given field data but failure to reject the null doesn't necessarily mean that the data follows the exact distribution and there could be other distributions that also fit the data (Höst et al., 2006).

4.3.3.3. Output Analysis

By accurately modeling processes in the system, output analysis allows the analyst to interpret the performance of processes and systems. Examples of output analysis could include the measurement of utilization rate of a machine in a factory or retail workers in a store, throughput rate in a warehouse, etc. The analysis can thereby be used to either understand current performance of sub-processes in an existing process or to explore and predict the performance of a new process (Laguna and Marklund, 2019; Liotta, 2012; Tako and Robinson, 2012). An important aspect of output analysis is also enabling the possibility of being able to compare similar scenarios with minor tweaks to perform different what-if scenarios (López-Pintado et al., 2024).

Since the input variables in a simulation model are stochastic, the output should also be treated as stochastic variables (Laguna and Marklund, 2019). This is important as there might be some operational setups which generate a very favorable outcome, but this could be due to statistical outliers and will not necessarily reflect the best setup in the long run. If you for example decide to flip a coin ten times, the outcome may be ten heads in a row, but this will be a very improbable scenario. Therefore, the analyst should be wary of taking one simulation's output at face value. However, even if the likelihood of getting heads ten times in a row is very low, it is still possible, and this outcome should be reflected in the model. By looking at mean values of the performance metrics and their variance, the analyst can further understand the performance and implications of a certain operational setup. To do this, the analyst must be wary of issues regarding sampling and sample sizes to ensure statistical validity and ability to draw conclusions that reflect the process' actual performance (Laguna and Marklund, 2019). This includes for example ensuring that the simulation model is performed in a sufficient amount of runs or time to see whether the process is stable or not. The choice of the amount of runs and time depends on the characteristics of the process. For example, is the process constantly operational every hour of the day? Are there resets or not? Laguna and Marklund (2019) distinguishes between different output analyses depending on the characteristics of the process in Figure 16 below.

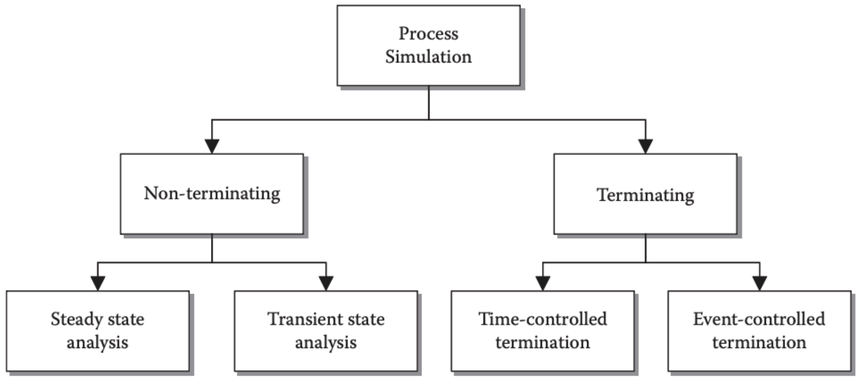

Figure 16: Analysis of output data according to simulation characteristics (Laguna and Marklund, 2019).

In Figure 16, a non-terminating process does not end naturally within a specific time horizon. This could for example be stock levels in a warehouse, where the final stock level at the end of the day is the starting stock level at the start of the next day and so on. These types of processes usually reach a steady-state condition in which the process state distribution doesn't change with time and is independent of the starting state of the simulation (Laguna and Marklund, 2019). Typically, non-terminating processes go through a transient state before reaching a steady state (Keramydas et al., 2017). For a non-terminating process, the transient period therefore represents the short-term performance, whilst the steady state represents the long term, stable performance - if the process is stable. During the transient period, the process state distribution is different from the steady state (Laguna and Marklund, 2019). To find the point where a process state changes from transient to steady state, the analyst can examine a line-plot of the output variable to see when its behavior changes. See Figure 17 for a distinction between the two states, where the two states are separated by the dashed, vertical line.

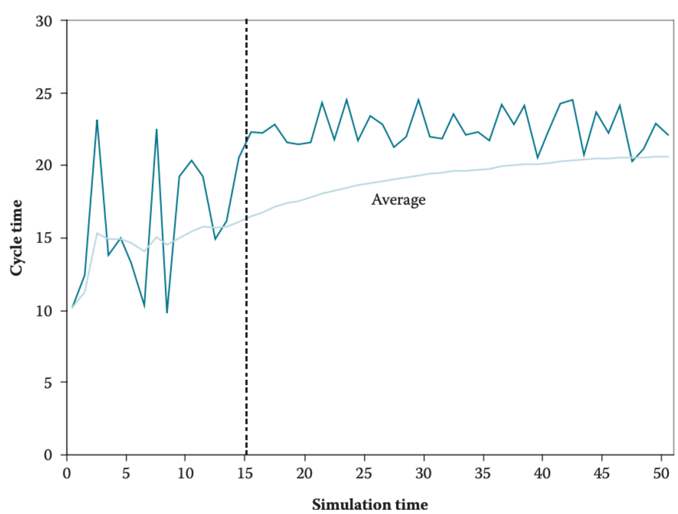

Figure 17: Line plot of cycle times and average cycle time (Laguna and Marklund, 2019).

A terminating process is usually one which starts from an empty state and finishes in an empty state (Laguna and Marklund, 2019). Here, the process terminates after a certain amount of time has passed and an example could be that of a retail store which has set opening hours. At the beginning of the day, the number of customers will be zero and at the end of the day it will be zero again, as the store closes. In these types of processes, steady state isn't necessarily reached as the store might not be open long enough for the process to reach it (Laguna and Marklund, 2019). In this scenario, the analyst should opt for simulating more independent runs of the same simulation setup to reach a sufficient sample size and ensure statistical validity to be able to draw conclusions about the process' performance.

4.3.3.4. Modeling Assumptions

When developing a simulation model where specific data - such as explicit downstream demand - is either unavailable or intentionally excluded from the system boundaries, fundamental boundary assumptions must be established to ensure the model functions logically. One theoretically supported method for handling such delimited scopes is the steady-state equilibrium approach. This approach relies on the *equilibrium assumption*, which dictates the rate of products made available at the origin (supply) is strictly equal to the rate at which they are absorbed at the destination (demand) (Fleischmann et al., 1998). Furthermore, this can be coupled with a *steady-state assumption*, which assumes that the products are absorbed at the destination at a given constant rate, and a *continuity assumption*, meaning the absorption happens in a continuous way (Fleischmann et al., 1998). A primary example of why this approach is necessary is the modeling of stock levels. In process dynamics, a "stock" is defined simply as an accumulation that is created by the difference between the inflow to a process and its outflow (Laguna and Marklund, 2019). Fleischmann et al. (1998) argues that this can be done by setting the destination's consumption flow (outflow) to a constant ready state that perfectly matches the average supply generation (inflow), and thus through this assumption the simulation successfully isolates the system's internal behavior (Fleischmann et al., 1998).

4.3.4. Conceptual Modeling for Simulation

Before a simulation model can be successfully implemented in computer software, the underlying real-world problem must be thoroughly understood and abstracted (Robinson, 2013). This vital phase is known as conceptual modeling, defined as the non-software specific description of a simulation model abstracted from the part of the real world it represents. Attempting to capture every operational detail of a complex system, such as a large-scale supply chain, is rarely feasible due to data and time constraints (Robinson, 2013). Therefore, the conceptual modeling process focuses on choosing what to model and what not to model, ensuring that the system is simplified to the appropriate level of abstraction (Robinson, 2013).

The development of a conceptual model serves as the critical bridge between physical reality and the intended simulation architecture by navigating between the *problem domain* and the *model domain*, as illustrated by Figure 18. In the problem domain, the initial step is *knowledge acquisition*, where the real-world problem is investigated to create a comprehensive *system description*. Once the system description is established, the process transitions into to the model domain through *model abstraction*. During this step, the complexities of the real-world system are processed into their most essential components by introducing necessary simplifications and assumptions (Robinson, 2013). Robinson (2013) claims that simpler models are highly preferred in simulation because they are faster to develop, require less data, and offer results that are easier to interpret.

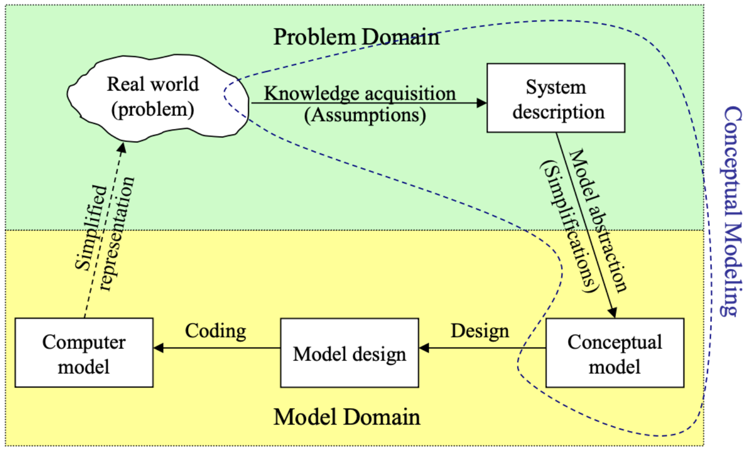

Figure 18: Artifacts of Conceptual Modeling (Robinson, 2013).

4.4. Conceptual Framework

To systematically evaluate RMC Nordic's simulation readiness, the theoretical domains explored in this chapter have been synthesized into a comprehensive conceptual framework (Figure 19). The framework utilizes an adapted version of Robinson (2013)'s conceptual modeling artifacts and framework to demonstrate how the literature provides the necessary theoretical support when investigating simulation readiness in logistics organizations. The framework is divided into three interconnected areas: the Problem Domain, the Model Domain and the culminating Simulation Framework.

Within the Problem Domain, literature concerning supply chain management, alignment and network complexity acts helps understand the problem situation. Theories regarding supply chain misalignment and decision-making architecture provide the foundation to understand the real-world problem situation at RMC Nordic. Furthermore, theories regarding structural logistics trade-offs are applied to theoretically frame and constrain the general modeling objectives.

The Model Domain illustrates how the physical logistics network is theoretically translated into a simulation architecture. Here, the literature explicitly dictates the necessary components for abstraction. Multi-objective logistics KPIs establish the desired outputs, while literature on network configurations and business process logic defines the model content, e.g., the network's nodes, activities and flow units. Finally, established theories on data granularity and informational prerequisites support the model inputs, ensuring the abstraction aligns with the data demands of simulation-based decision support.

Ultimately, these theoretical components converge in the Simulation Framework, which is supported by literature covering IT governance and digital enablers in supply chain contexts, organizational alignment, technical prerequisites and conceptual modeling into a practical road-map. The conceptual framework provides a theoretical foundation required to assess RMC Nordic's current gaps and guide their future adoption of simulation-based decision support.

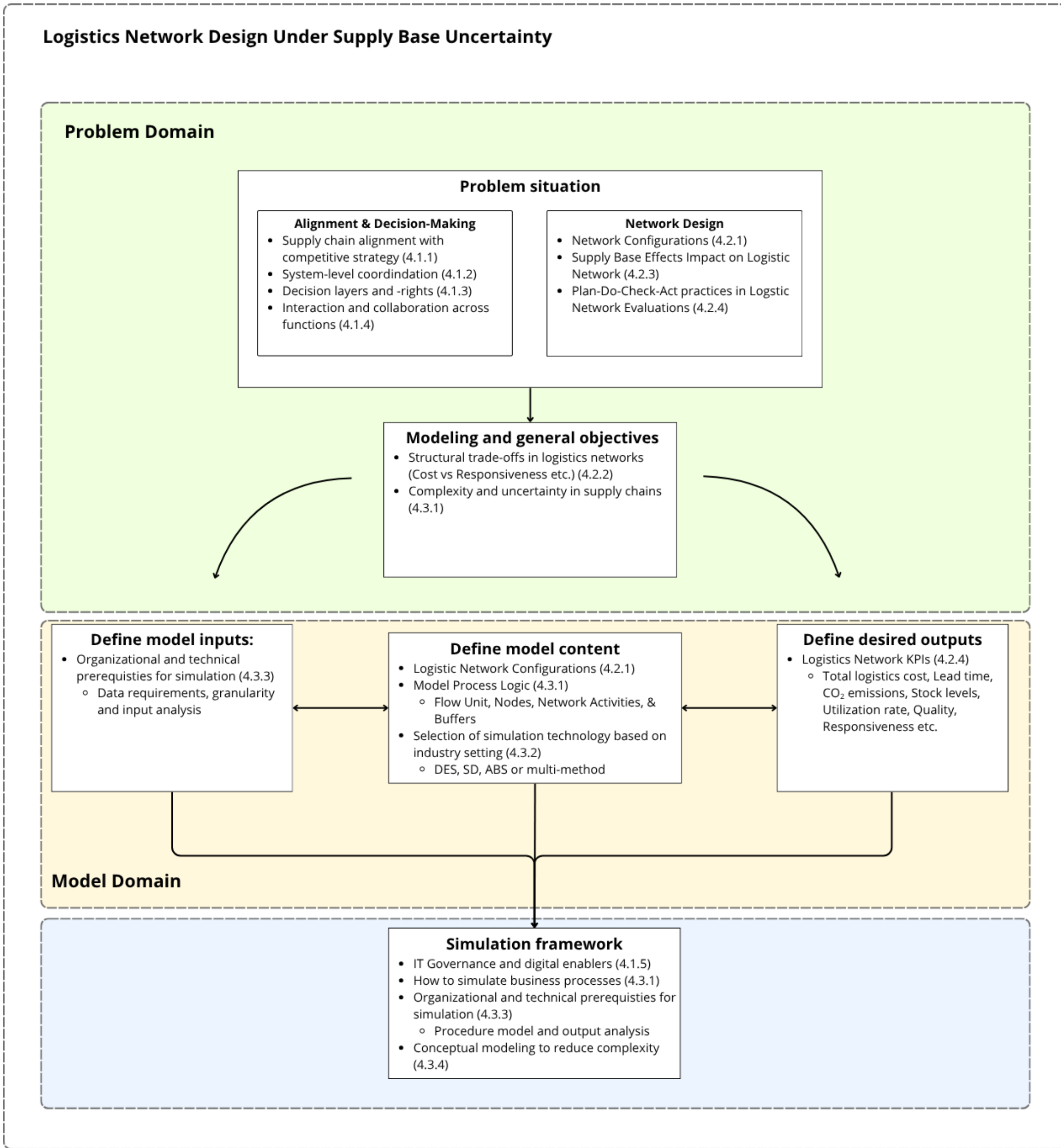

Figure 19: Conceptual Framework based on (Robinson, 2013)'s conceptual modeling framework.

5 Empirical Findings

This chapter presents the empirical findings collected through the interviews, the archival records, observations on site and informal socialization process with Scania employees and relevant stakeholders.

5.1. Organizational Structure

Scania's global logistics function is organized into several primary areas, one of which is Production, Procurement and Logistics. Within this function, the logistics organization is geographically structured into regional units, each supported by a corresponding Regional Material Control (RMC) center. In total, four RMCs exist: RMC Nordic, RMC Europe, RMC Latin America, and RMC Asia. As outlined in Chapter 2, the scope of this thesis is delimited to the RMC Nordic division. The organizational structure of RMC Nordic, within the broader context of Scania Logistics Nordic, is illustrated in Figure 20.

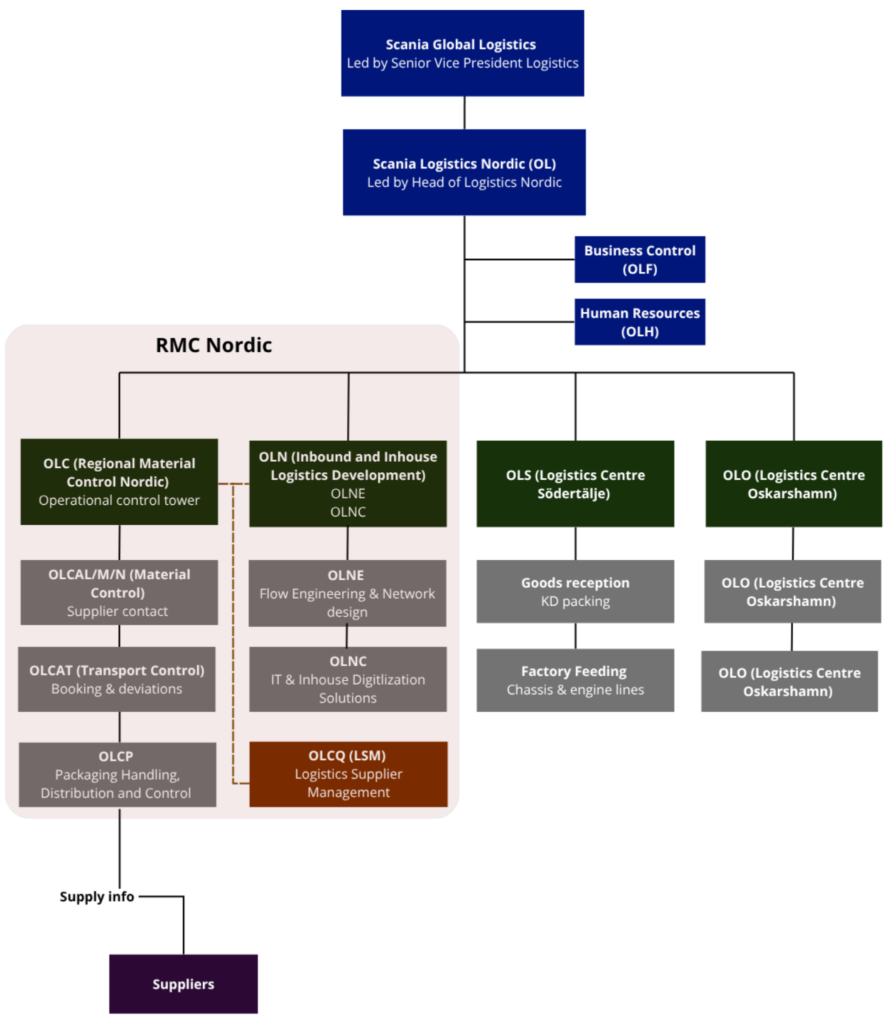

Figure 20: RMC Nordic organizational structure.

5.1.1. RMC Nordic

RMC Nordic operates as a centralized logistics control tower, responsible for coordinating inbound material flows from suppliers to Scania's production units within the Nordic region. The operational scope is extensive, covering logistics activities across eight countries, three active cross-docks and approximately 400 active suppliers. On a daily basis, the network handles around 11,500 active part numbers, 1,300 material orders and 350 transport loads, illustrating the high level of complexity managed within the organization. To handle this complexity, RMC Nordic is both structurally and conceptually divided into two main domains: *Operation* and *Development*. This division reflects a separation between the daily execution of logistics activities and the long-term development of the network and processes. The structural overview of RMC Nordic is illustrated in Figure 21.

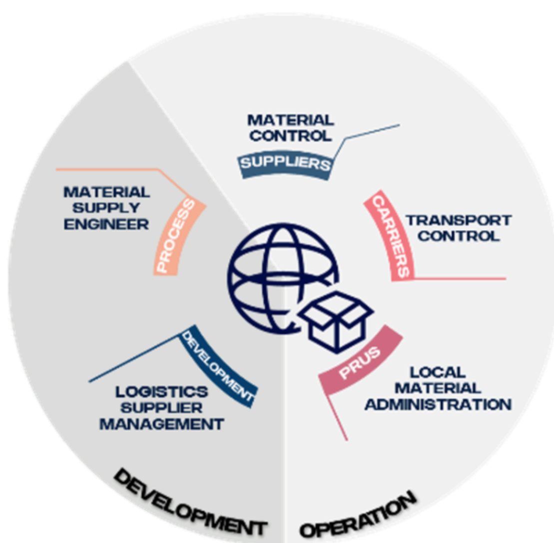

Figure 21: RMC's two structural divisions.

Operation

The operational domain is responsible for the daily execution of the inbound logistics network, ensuring that materials are delivered to production units according to plan and that deviations are managed in a timely manner. This domain is primarily represented by the Regional Material Control (OLC), which acts as the central control tower of the inbound network. Within OLC, responsibilities are further divided into specialized functions. The Material Control function (OLCAL/M/N) maintains daily contact with suppliers, ensuring that call-offs are fulfilled and that material availability is secured. In parallel, the Transport Control function (OLCAT) manages carrier interactions, transport bookings and operational deviations within the transport network. Additionally, the Packaging Handling, Distribution and Control function (OLCP) is responsible for the management and distribution of packaging materials required for inbound flows.

Development

The development domain focuses on improving and evolving the logistics network through process development, network optimization, digitalization initiatives and supplier capability assessments. A central actor within this domain is Inbound and Inhouse Logistics Development (OLN), which is divided into several specialized teams. The Flow Engineering and Network Design team (OLNE) is responsible for designing transport networks, conducting carrier tenders, and optimizing material flows. Complementing this, the IT and digitalization team (OLNC) focuses on the implementation of digital tools and systems, including large-scale initiatives such as the roll out of common Enterprise Resource Planner (ERP) systems across the Scania organization. In addition to OLN, Logistics Supplier Management (LSM), also referred to as OLCQ, plays a key role within the development domain. LSM's responsibilities include supplier development, logistics audits, crisis management, coordination of Landed Cost Estimation (LACE) and the evaluation of suppliers' logistics capabilities in supplier selection processes.

Inhouse Logistics (Parallel to RMC Nordic)

While RMC Nordic (OLC, OLN, and LSM) functions as a control tower responsible for planning, network design and supplier coordination, the physical handling of goods is managed by parallel units within the broader Scania Logistics Nordic organization. These activities are primarily carried out at logistics centers such as OLS in Södertälje and OLO in Oskarshamn. These facilities are responsible for goods reception, cross-docking, repackaging activities and factory feeding operations directly supporting assembly lines.

5.1.2. TRATON Group Integration

A massive strategic shift currently reshaping this organizational structure is the integration into the broader TRATON Group. The ”Traton Group Logistics” initiative aims to build common capabilities and consolidate inbound transport volumes across Scania, MAN, Navistar and Volkswagen Truck & Bus to support a shared TRATON Modular System. This integration presents a significant network design challenge due to fundamentally contrasting logistical operating models between the brands. Scania operates a highly in-sourced control tower model, taking direct, centralized control over transport planning and flow optimization to achieve continuous steering and transparency. MAN on the other hand, outsources their transport planning. The ongoing integration towards a ”Common Inbound Transportation Network” aims to harmonize these different approaches through joint tendering, shared cross-docks and unified IT platforms.

5.2. Customers, Suppliers and Products

While RMC Nordic at Scania doesn't have direct contact with customers buying Scania's finished products, it is still relevant to have a broad level view of the products that Scania sells and to who. The reason for this, is that the types of products that are sold to what customers informs what type of material to be handled in the inbound logistics network of RMC Nordic, as well as what suppliers are contracted to produce the parts and components that will be handled in the network.

5.2.1. Customers

As mentioned previously in Chapter 2, Scania manufactures and sells heavy vehicles such as trucks and busses, as well as engines, industrial batteries and related services. Between 2024 and 2025, Scania's Customer Insight team held 63 interviews with customers to gather insights and opportunities (Scania, 2025). While the report explicitly states that "the material does not represent a complete view", the sample size is deemed big and deliberate enough to serve as representative for Scania's customer base in this contextually establishing section. A summary of the customer profiles of Scania can be viewed in Figure 22.

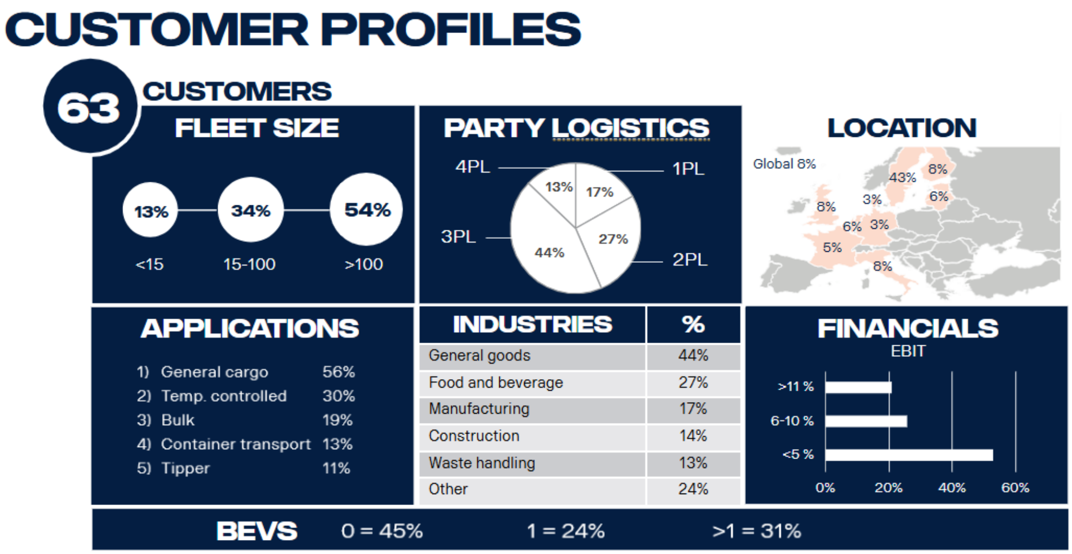

Figure 22: Distribution of Scania's customer profiles (Scania, 2025).

As can be seen in Figure 22, while customers are quite evenly distributed between different categories, the customer profiles tend toward the larger and more general options. Worth noting is also that applications and industries have significant portions of customers in specialized goods transport and handling. For inbound logistics at Scania, this translates into a wider variety of components and configurations that must be managed, including specialized equipment for temperature control or bulk handling. Increased product variety will lead to a more diversified article portfolio and consequently more complex material planning. Interviewee S_i, Senior Advisor Global Procurement, says that this is enabled by Scania's modular production approach, which enables them to provide customers with "almost exactly what they want". Interviewee S_i further explains that while this is very attractive to customers, it creates a strain on the predictiveness of article volumes.

Finally, the BEV adoption levels show that 45% of customers have no electric vehicles, 24% have one, and 31% have more than one. This indicates that electrification is present but unevenly distributed across the customer base. For inbound logistics, this introduces a transitional complexity, as both conventional and electric vehicle components must be managed in parallel. Interviewee S_i, also alludes to the uncertainty as to what the mix will be in a few years and states that this is very dependent on the industry of electric vehicles as a whole. The coexistence of different powertrain technologies increases the diversity of inbound material flows which needs to be taken in consideration when deciding the supplier base, inventory strategies and sequencing processes to accommodate the differing production requirements.

5.2.2. Suppliers and Incoming Material

As previously mentioned, RMC Nordic manages approximately 400 active suppliers. Interviewees K_i and L_i explains that RMC Nordic is responsible for suppliers geographically located in the Nordic countries, the Baltics and Poland. While they only manage suppliers within these specific regions, they are still responsible for delivering the material from these suppliers to all of Scania's production units globally (interviewee D_i and I_i). For parts destined for overseas productions units (such as in Brazil or China), RMC Nordic's responsibility entails managing the flow from the Nordic supplier's gate down to a central consolidation points, such as the one in Hasselt, Netherlands (Interviewee G_i).

Furthermore, every supplier is assigned to specific material planners and flow engineers who can choose to route shipments from them through the network's cross-docks (Interviewee B_i). RMC Nordic's three active cross-docks are located in Jönköping (Sweden), Nykvarn (Sweden) and Poznan (Poland). The Jönköping cross-dock handles suppliers located in southern Sweden, Norway, and Denmark, Nykvarn handles suppliers located in northern Sweden, Estonia and Latvia and the Poznan cross-dock handles suppliers located in Poland and Lithuania (Interviewee K_i and L_i). The volume split between each cross-dock can be seen in Figure 23 for 2026's first quarter volumes for batch parts. The figure is based on data retrieved from Scania's internal RMC PowerBI reports and reflects aggregated flows between cross-docks and PRUs, a flow that is named by Scania as Trunk Load (TL). It should be noted that sequence part data is not included, which limits the completeness of the presented volumes. It should also be noted that this covers the cross-dock outbound volume and does not account for volumes for material provided by suppliers. However, the figure provides a representative overview of the main inbound flow structure within the RMC Nordic network

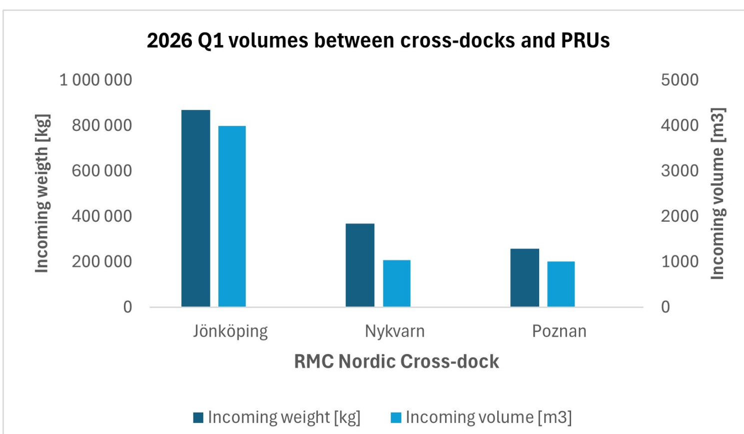

Figure 23: Cross-dock outbound volumes in Scania's RMC Nordic network during Q1 2026, measured in weight (kg) and volume (m³) (Scania, 2026).

RMC Nordic manages a highly complex product portfolio, with components ranging widely from traditional chassis and engine parts to new materials required for the transition toward BEVs (Interviewee J_i and Interviewee M_i). A critical distinction within this portfolio is the differing call-off logic between batch and sequence parts. Batch parts are ordered in fixed, standardized quantities (e.g., full pallets) and are planned using long-term schedules, often forecasted up to year in advance according to the Head of Scania Logistics Nordic (Interviewee I_i). The same interviewee, explains that in contrast, sequence parts are often custom-ordered to fit a specific truck chassis on the assemble line. Because they are directly tied to specific customer orders and production sequences, they have much shorter planning horizon - typically just a few weeks. Interviewee D_i, clarifies that sequence parts must arrive at the factory in the exact order they will be assembled, which heavily dictates how they are physically handled, routed and whether they can be consolidated in the transport network.

Furthermore, Scania's highly flexible modular product system makes it nearly impossible to accurately forecast future volumes at an individual part level (Interviewee S_i). This forecasting challenge is fundamentally driven by Scania's strategy of "open combinatorics", which actively avoids grouping components into predefined, standardized models (Scania AB, 2021). Figure 24 presents a historical overview of Scania's modular components, which together form the so-called *Bygglådan* (the Construction Box). Scania's modular system allows customers to freely combine different performance properties to create unique, tailor-made solutions for their customers.

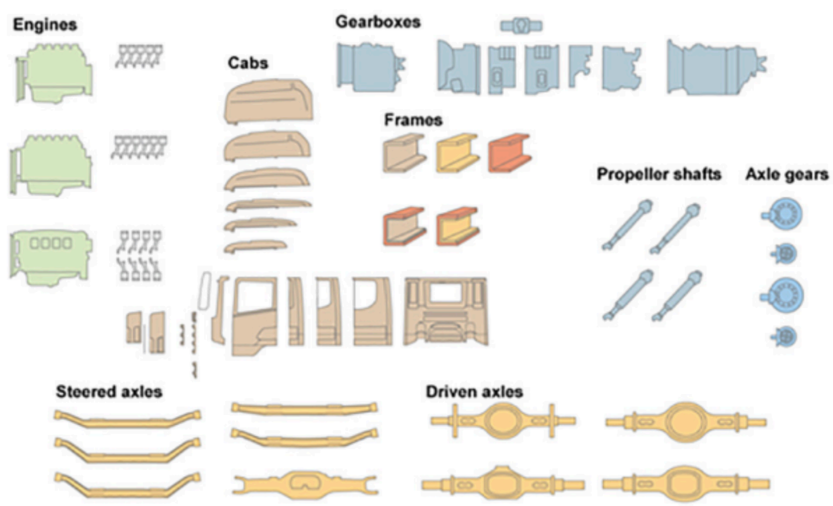

Figure 24: Scania's traditional modular component system, Bygglådan (Scania AB, 2021).

Because of their wide product offering, customers are allowed to make late changes to their orders and the exact vehicle variant is often defined very late in the supply chain. To manage this uncertainty in the short-term time perspective and without compromising on the modular system, Scania utilizes a Variant Coded Product Structure (Scania AB, 2021). This system acts as a dynamic translation layer between the customer's ordered configuration and the actual hardware components that will be needed for production. While this late-specification and modular approach maximizes customer value and operational flexibility, it means that the final combination of physical components is not locked in until the actual customer order is placed. Consequently, predicting exact inbound order volumes at a specific component level over a longer time horizon can become volatile, as confirmed by Interviewee S_i.

5.3. Process Mapping

In order to be able to create a simulation model of the inbound logistics network at Scania, the end-to-end process with its inherent sub-processes needs to be understood. Based on the interviews, archival records and validation with Scania employees, the entire process, from a customer order being registered to a component or part being delivered at a production line, is described. End-to-end, the process can be split into the three distinct stages: Procurement, Flow engineering and tendering, and Transport as per the flowchart in Figure 25. The following sections will explain each stage in detail.

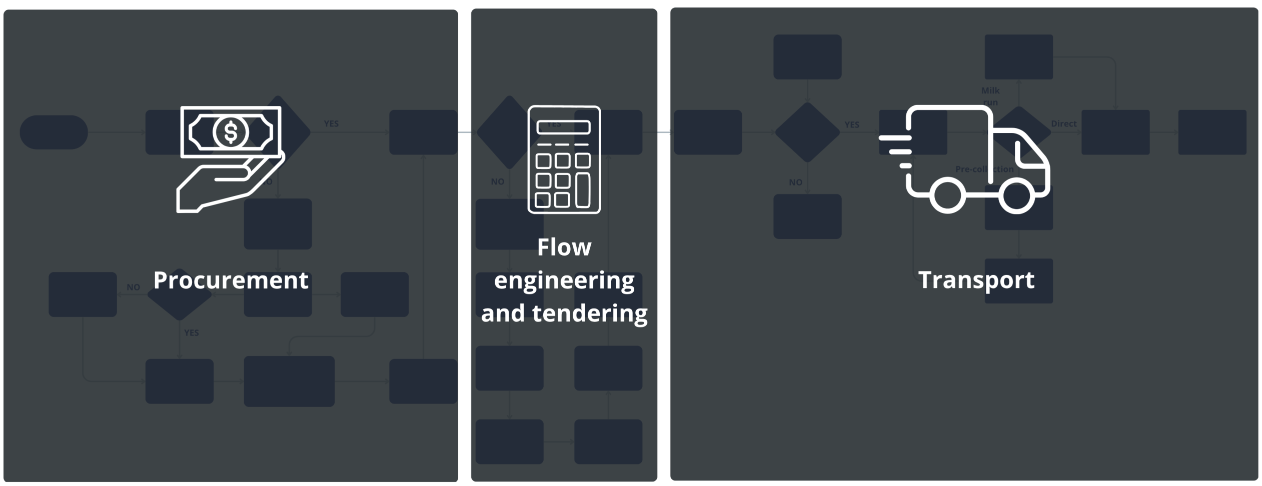

Figure 25: The three overarching stages enveloping the processes from customer order placed to goods delivered at production line.

5.3.1. Procurement

If components or parts in an order can't be fulfilled by current supplier capacity, a procurement process is initiated to find a new supplier that can fulfill the demand. The flowchart for this process can be found in Figure 26. The entire chain is driven by the actual demand for vehicles. Unlike previous production schedules that relied purely on forecasts, Scania now plans based on "actually ordered trucks" where a real buyer exists behind the requirement (Interviewee B_i). The Supply Chain Planning (OP) organization acts as the "start of the chain" by setting strategic production capacity plans that can stretch up to 10 years into the future (Interviewee W_i). On a more tactical level, they decide on the production program every four weeks, which defines exactly what volumes and types of vehicles will be produced (Interviewee E_i).

Once the demand is established, procurement evaluates if the current supplier base can fulfill the upcoming requirements defined by OP and if a new article is needed, a project purchaser is responsible for finding a supplier for this article (Interviewee S_i & Interviewee U_i). If new components or additional capacity are required, Procurement initiates a formal sourcing case where they typically identify and nominate a "shortlist" of three to five potential suppliers to compete for the contract (Interviewee A_i & Interviewee U_i). For these shortlisted candidates, Procurement sends a formal request to the LSM team to receive a supplier rating and LACE estimation (Interviewee A_i). If a shortlisted candidate is an existing supplier, LSM provides a rating based on historical performance, including delivery precision and quality deviations over the last year (Interviewee A_i). For new suppliers - where no current rating exists - LSM performs a physical supplier audit where they use established industry standards to score the suppliers' internal logistics, planning and material handling, using these to generate a new rating for the supplier in question (Interviewee A_i & Interviewee W_i). They can also utilize an internal Volkswagen Group system to see if other brands in the group have audited the supplier within the last three years (Interviewee A_i). When a supplier rating is available, this rating is provided to the Procurement team along with the LACE estimation.

The LACE calculation is the estimated total cost of transporting the article to the production unit and serves as a measurement of the ”total logistics cost” (Interviewee A_i). For standard European flows (Euronet), this is done via an automated tool where users enter the weight, volume, annual consumption, etc., while overseas or complex flows are calculated manually by LSM engineers (Interviewee A_i & Interviewee D_i). The LACE calculation is also provided to the Procurement team.

Once Procurement has received the logistics inputs, they combine them with other departmental evaluations to build business cases based on a method which factors in five categories: Technology, Quality, Delivery, Cost and Sustainability (TQDCS) (Interviewee U_i). These business cases are then reviewed by the Sourcing Board which is a cross-functional forum that includes management from various departments (Interviewee A_i). The board reviews the TQDCS performance and the total ”B-price” (article price + LACE) before officially awarding the contract to the chosen supplier (Interviewee S_i).

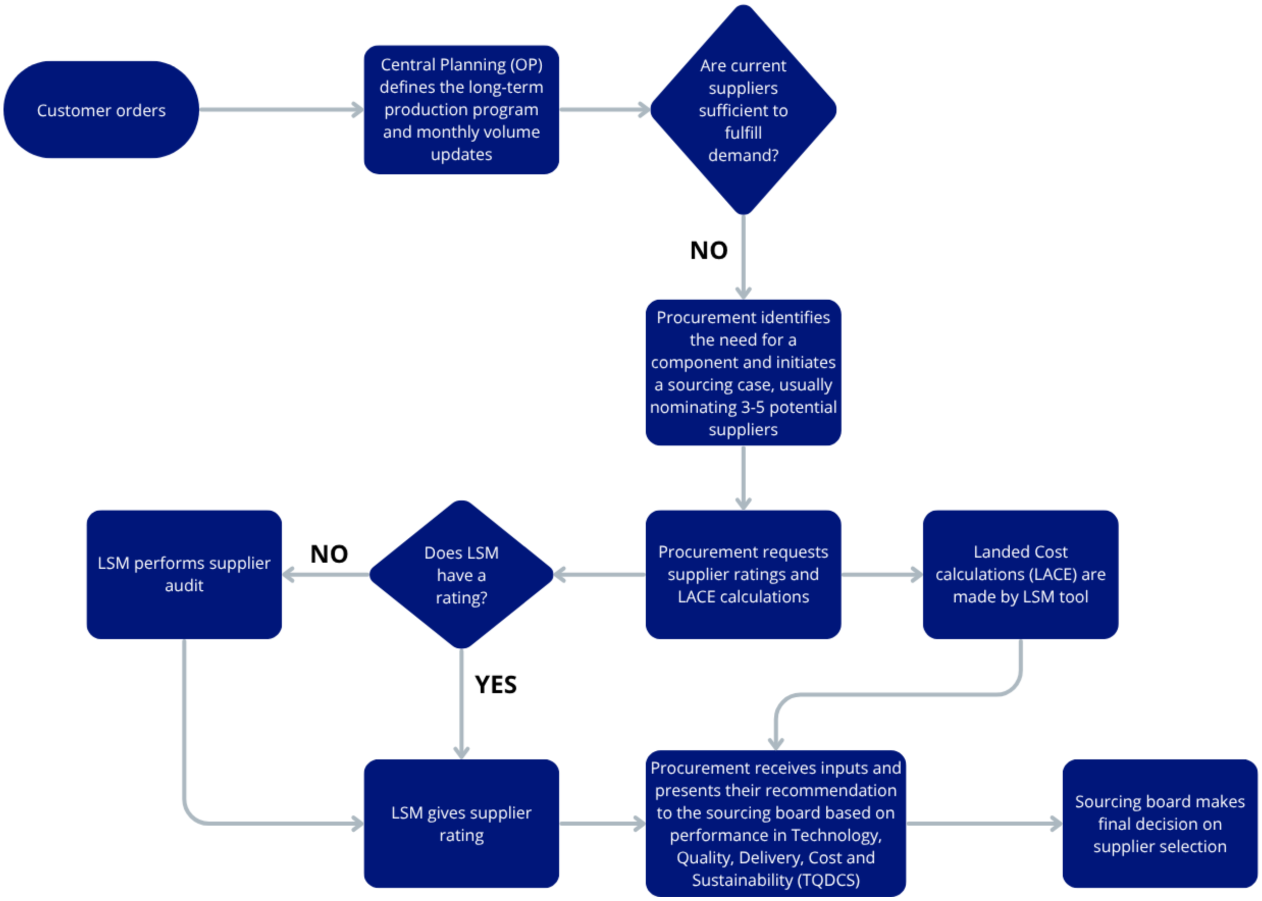

Figure 26: Flowchart detailing the procurement process for new components.

5.3.2. Flow Engineering and Tendering

Once suppliers for a component or part exist, the logistics around transporting said products from the suppliers to the production units needs to be engineered and contracted, as Scania doesn't transport products using an internal vehicle fleet. A flowchart of this process can be found in Figure 27.

Firstly, OLNE designs the transport routes. They are responsible for the strategic architecture of the network, deciding on the most efficient routes and determining if goods should travel as direct flows or via a cross-dock (Interviewee D_i, Interviewees K_i & L_i and Interviewee P_i). This analysis also includes setting parameters such as the number of pick-up days and whether to implement milk runs for regional efficiency (Interviewee D_i). Interviewee P_i, Group Manager of Inbound Network Design and Flow Engineering explains that OLNE's primary responsibility is the decisions of whether flows should be direct or routed via cross-docks (pre-collection). Interviewees K_i & L_i, Flow Engineers, note that this decision is heavily influenced by volume. For instance, small volumes are typically routed through a cross-dock to maximize efficiency, while large volumes might justify a dedicated direct flow. To aid the design of the transport flows, the OLNE team uses the coming 90-days production forecasts to estimate the future volumes transported in the various flows and adjusts the flow design accordingly (Interviewee P_i & Interviewees K_i & L_i). After a route is implemented, the performance of the design is continually monitored using transport fill rates as the primary KPI

(Interviewees K_i & L_i).

Interviewee P_i, Group Manager of Inbound Network Design and Flow Engineering states that OLNE currently spends a lot of time leading projects to set up new transport tenders. When a route lacks a contracted carrier, OLNE drafts a technical specification (Interviewee X_i). This document defines the required trailer types, precise pick-up and delivery locations and the lead times necessary to meet production requirements. Once the specifications are finalized, the Indirect Procurement team (SALA) officially launches the tender into the market in which transport carriers can submit bids on the tender (Interviewee X_i). After receiving the bids, Flow Engineering conducts a technical evaluation, meaning that they filter out carriers that cannot meet the specified requirements or lack the necessary equipment, narrowing the bids down to a list of "technically approved" bids (Interviewee X_i). SALA then conducts multiple negotiation rounds, pushing for price reductions and more sustainable transport alternatives. The final negotiated prices are then sent back to Flow Engineering who build different scenarios to visualize trade-offs in CO_2 emissions and cost (Interviewee X_i). Procurement then produce a proposal which they present to the relevant Traton steering group. The steering group then reviews the proposal and makes the final decision of which carrier to award the transport contract. These contracts are typically signed for a three-year period with the option for a two-year extension (Interviewee X_i). Once the transport lane is set up in the system and the carrier is contracted, the network is considered ready for operation and RMC are free to trigger call-offs from the supplier (Interviewee F_i).

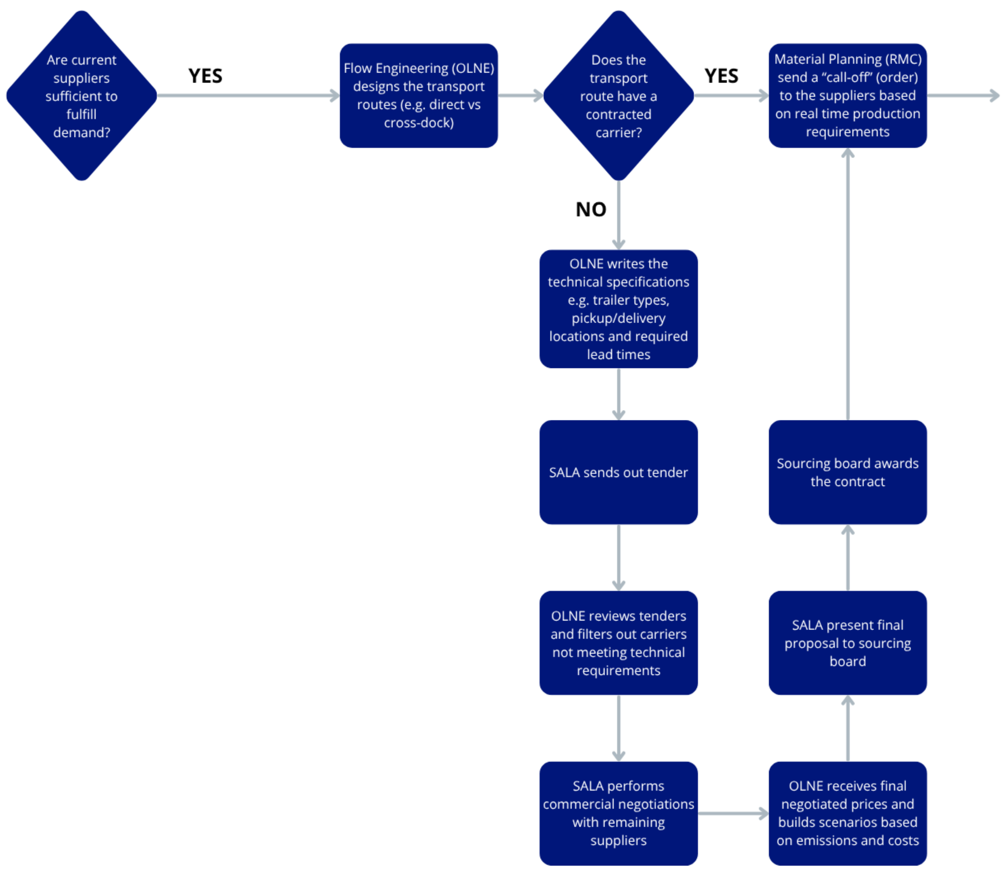

Figure 27: Flowchart detailing the flow engineering and tendering process.

5.3.3. Transport

Once RMC is ready to call off suppliers, the goods need to be transported from the suppliers. As previously mentioned, Scania contracts external carriers, requiring coordination and communication. a flowchart of the process from call-off to production line delivery can be found in Figure 28.

The transport process is started when RMC sends a "call-off" to suppliers based on real time production requirements (Interviewee F_i & Interviewee B_i). These requirements are derived from the production program defined by OP, reflecting annual customer orders (Interviewee F_i). RMC is responsible for ensuring that the required material is shipped in the correct quantity to meet the production schedule (Interviewee F_i). Once the call-off is received, the supplier books a pick-up with the contracted carrier, usually one day in advance (Interviewee B_i). RMC monitors the system to ensure suppliers and carriers are adhering to their contracts (Interviewee B_i). If a supplier repeatedly fails to book transport on time or deviates from the agreed communication process, the LSM team is contacted. LSM acts as a support function, performing audits or visiting the supplier on-site to resolve process issues and ensure future delivery precision (Interviewee B_i).

Once a carrier has been booked for a pick-up, the carrier arrives at the designated pick-up location, and drives the shipments as per OLNE's flow optimized design (Interviewee D_i). These flows can vary depending on the volumes to be shipped from different suppliers. For high-volume or critical parts, the carrier takes the goods directly from the supplier to a production unit or its associated Logistics Center (Interviewee D_i & Interviewees K_i & L_i). For smaller volumes which can't fill an FTL, a carrier often follows a route to pick up smaller volumes from multiple suppliers in the same region before heading to a Logistics Center (Interviewees G_i, K_i & L_i). Flows routed via a cross-dock are regularly referred to as "Pre-collection" internally at Scania. For these flows, goods are picked up (often via milk-run) and dropped of at a cross-dock such as those in Jönköping, Nykvarn or Poznan (Interviewees K_i & L_o). A different carrier is often contracted for the flows from cross-docks to production units and logistics centers and these are usually direct flows since the volumes tend to be high due to the consolidation in the cross-dock (Interviewees M_i & F_i).

Once the goods arrive at the gate at a logistics center, In-house Logistics takes over the ownership of the process (Interviewee E_i). First and foremost, the parts are registered to let material planners see that they have arrived (Interviewee N_i). The shipments are stored within the Logistics Center or warehouse until needed and based on the production rate, parts are moved from storage to the production lines (Interviewee N_i).

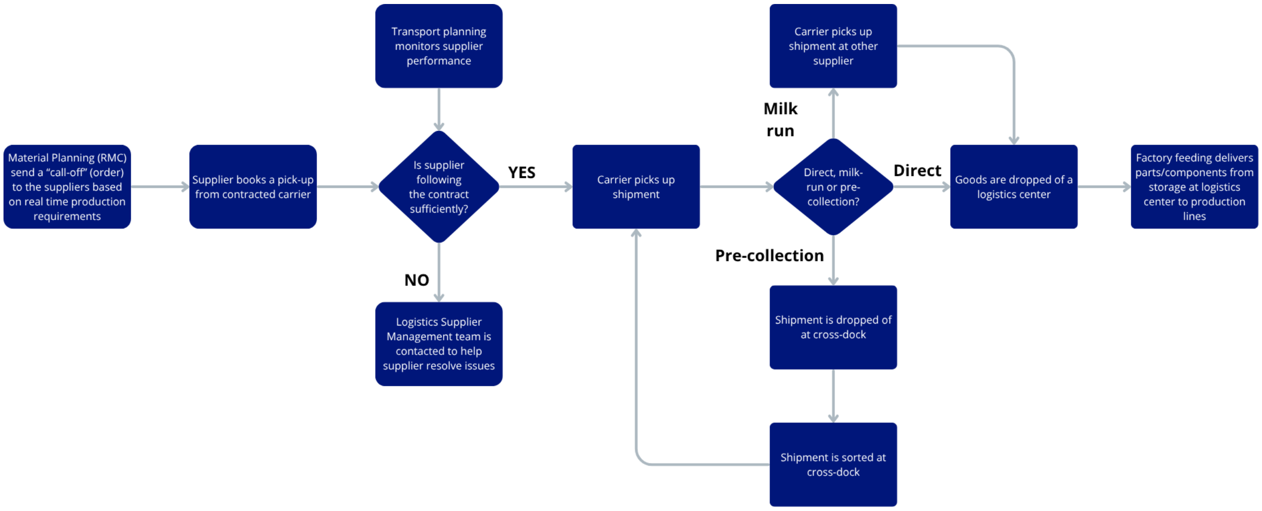

Figure 28: Flowchart detailing the transport process from supplier to production lines.

5.4. Decision-Making in Network Design

The foundational constraint for any network design at RMC Nordic is the supplier base, which is, as described in the previous section, determined by the Procurement department. While the supplier selection process is formally guided by the TQDCS framework, interviewee I_i and U_i claim that price often becomes the dominating factor in practice. Additionally, to increase supply chain resilience and mitigate risks, Procurement has increasingly begun implementing multi-sourcing strategies for certain flows (Interviewee S_i). Once the supplier base and the purchased volumes are established, the responsibility shifts to OLNE, who decide exactly how the material will be picked up and delivered to Scania's PRUs. To structure these flows, Flow Engineers utilize a standard set of transport archetypes. These options dictate whether material should be transported directly or via cross-docks, and include:

- **FTL (Full Truck Load)**: Fully utilized trucks driving directly from a supplier to a PRU.
- **LTL (Less Than Truck Load):** Not fully utilized trucks driving from a supplier via a potential cross-dock, or directly to a PRU.
- **MR (Milk Run):** A routed loop that picks up goods from multiple suppliers to fill a truck before driving directly to a PRU.
- **Pre-collection:** The transport leg between a supplier and a cross-dock. This can be executed as a cross-dock MR, meaning that goods are picked up from multiple suppliers before dropped off at the cross-dock.
- **Trunk Load:** The consolidation, high-volume transport leg moving from a cross-dock directly to a PRU.

Figure 29 displays the distribution of the different transport types for flows from suppliers to cross-docks. It should be noted that pre-collection cannot be distinguished in this breakdown and that is because it is included in the MR share as a cross-dock MR transport type.

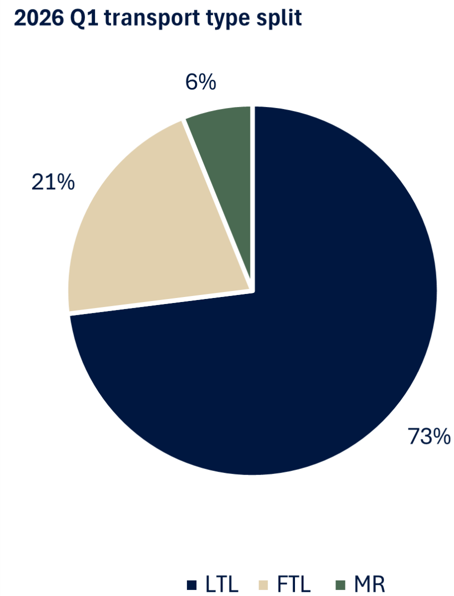

Figure 29: Transport type within Scania's RMC Nordic network during Q1 2026, showing the share of LTL, FTL, and Milk Run flows (Scania, 2026).

5.4.1. Case Calculations and CO2 Emissions

The decision of which transport archetype to assign to a specific flow is heavily driven by the objective to maximize the fill rate of the trucks being utilized. According to Scania's internal Flow Engineering guidelines, the efficiency of a network design depends on balancing three critical factors:

1. Minimizing unnecessary travel distances.
2. Reducing the number of touches and handling steps in the flow.
3. Managing the trade-off between transport costs and stock holding costs.

The target fill rate for RMC Nordic's transports are 80% and the average fill rate for transport loads in Q1 2026 (9982 transport loads in total) amounts to 68,02%. Furthermore, only 34,6% of the loads achieve a fill rate in line with the 80% target (Scania, 2026). To facilitate this fill rate efficiency, RMC Nordic's cross-docks are strategically located in close relation to large supplier collection areas. This strategic placement allows flow engineers to consolidate smaller, regional LTL shipments into high-fill-rate TL transports over long distances.

Case Calculations

To determine whether a specific transport flow should be routed directly to a PRU or via an intermediate cross-dock, Flow Engineers utilize a standardized routine known as *Case Calculation*. This evaluation method calculates theoretical cost and CO_2 impact for a specific flow across different scenarios by altering the number of Pick-Up Days (PUD). By comparing the yearly cost and emissions of a direct transport setup against a cross-dock set up with varying PUD frequencies, the engineers can identify the most optimal solution. In practice, these case calculations are primarily performed using an Excel-based tool and the routine dictates exactly how current KPIs are evaluated prior to implementation.

The Case Calculations can, among other things, be used to calculate logistic costs. In the current routine, logistics costs are determined using historical forecast data (average forecasted weight, volume, and package count per pick-up), and excludes outliers like holidays and adjusting for sequential part orders. The routine defines specific calculation structures depending on the transport trailer type. For *Direct Transports* the calculation converts the required shipment volume (m^3) and weight (*kg*) into ”pay-weight” (PW) and ”Load Meters” (LM) using standardized conversion factors (1 m^3 = 280 *kg*, 1 LM = 1950 *kg*). The required LM is rounded up and the cost is extracted from regional rate tables based on the origin postcode and destination ”cluster”. For cross-dock transports (indirect), the total costs for flows moving through an intermediate cross-dock is broken down into three distinct operational components:

1. *Pre-collection Cost:* The cost of picking up goods from the supplier. This calculation must account for ”other pre-collection” goods, meaning the PW includes both the volume destined for the specific PRU in scope, as well as goods picked up from the same supplier but destined for other cross-dock locations.
2. *Handling Cost:* The processing cost incurred at the cross-dock. Depending on the specific facility, this is measured either as a cost per handled 1000 kg (Nykvarn and Poznan) or as a cost per handled pallet (Jönköping).
3. *Trunkload Cost:* A fixed standard price applied for a full truck, depending on the trailer type (13.6 or 20 LM) traveling from the cross-dock to the final destination. The Excel tool automatically calculates the proportional cost based on the specific LM required by the case.

Furthermore, the total logistics costs account for inventory holding expenses. Within the case calculation routine, this is estimated by matching the flow to a suitable warehouse profile from a predefined list. In cases where the exact destination warehouse is not represented in the tool, an approximation is made by selecting a warehouse profile that most closely resembles the physical and operational characteristics of the intended facility

CO_2 Emissions

To evaluate the CO_2 emissions generated by Scania’s inbound logistics network, Scania uses an external calculation tool called Proxio, which calculates emissions in carbon dioxide equivalents (CO_2e) based on global standards aligned with the international organization Smart Freight Centre. The core mathematical formula used by Proxio for road transports dictates that emissions are the product of the driven distance, the fuel’s specific emission factor, and the vehicle’s fuel consumption. The fuel consumption is highly dynamic. It is calculated as a baseline empty fuel consumption (FC_e) plus the additional consumption required to move the specific payload, modeled proportionally against the truck’s maximum weight capacity. To accurately reflect real-world logistics inefficiencies, Proxio incorporates two critical business rules into this calculation:

- **Empty Running:** The tool assumes that trucks do not always drive fully loaded on return trips. Therefore, the total distance calculated includes both the loaded distance and an "empty running" distance. By default, empty running is assumed to be 17% of the total distance driven and the emissions for this segment are calculated based on an empty truck profile.
- **Threshold on Fill Rate:** To prevent unrealistic emission allocations for highly inefficient shipments, Proxio applies a strict threshold rule. If a road shipment's weight or volume fill rate is 60% or lower, the tool artificially increases the truck's fill rate to 60% before calculating the total emissions and then allocates Scania's share proportionally based on weight.

Furthermore, the tool is capable of handling multi-leg transports (e.g., picking up via road, transferring to rail and delivering via road) by applying specific emission profiles, such as vehicle type and energy carrier (Diesel or HVO100), to each distinct leg of the journey. In the current Case Calculation routine, Flow Engineers use this tool statically, inputting the average forecasted case weight and assuming 100% utilization for consolidated TL's from cross-docks.

While the Case Calculation tool is highly focused on cost and CO_2, modifying the network design by altering the PUD inevitably affects delivery frequencies, lead times, and batch sizes. For example, reducing PUDs from 5 days a week to 1 day a week might mathematically represent the best solution from a CO_2 perspective. However, this leads to massive batches arriving simultaneously. To manage this, the routine requires engineers to estimate the effect on the goods reception at local PRU's. The engineers must verify the total amount of goods received against the maximum capacity of the goods reception area. If the proposed PUD change breaches the maximum capacity, corrective actions must be taken. Furthermore, an uncertainty margin (e.g., 5% of current yearly cost) is calculated and compared against the savings potential to determine if a change is ultimately feasible.

5.5. External Parties

The interviews with the external simulation experts and consultants highlight a strong consensus on the methodological and practical prerequisites for successful simulation projects. An clear theme across all interviews is the necessity of establishing clearly defined, bounded objectives to avoid creating overly complex models that fail to deliver value. Interview R_e warns that industrial simulation projects often become "gigantic" and "a complete mess" without a clear purpose, that often leads to the development of invalid models. Similarly, interviewee T_e emphasizes that building a comprehensive, open-ended model designed to answer any potential question is a "recipe for disaster". The interviewee advices companies instead to "start with the objectives of the project". To manage this complexity, the experts collectively advocate for hierarchical, iterative approach. Interviewee Q_e advices to "start small, start simple" and only dive into deeper granularity when high-level approximations prove insufficient. Interview T_e agrees, suggesting simulation developers initially to use a "limited set of data, plenty of black boxes". This is further supported by interviewee V_e, that claims that most successful simulations project "start with a rather small question that you build upon", and strongly advices against modeling at an overly detailed item level, and instead suggests that companies must "lift and aggregate" data into a broader context.

Regarding data availability, the experts agree that striving for flawless data is an unrealistic barrier to entry. Interviewee Q_e states clearly, ”I’ve never seen perfect data .. perfect data does not exist anywhere”. When faced with missing or unreliable data, the experts suggests practical workarounds rather than stopping the project. Both interviewee’s Q_e and T_e specifically recommend utilizing subject matter experts to estimate the minimum, maximum and most likely times or costs to ”fit a triangular distribution” when data is limited. Interview V_e builds upon this approach by arguing that to get a project moving, it is better to use an ”average” for different data points rather than waiting to find exact historical figures. Interviewee R_e also explains that when dealing with uncertain data, relying on methods such as estimations and conducting sensitivity analysis are critical to determine how much the data variations actually impact the final results.

A further consistent theme across the interviews is the importance of establishing clearly defined KPIs and aligning these with existing performance measurement frameworks to ensure both the effectiveness and usability of the simulation model. The experts emphasize that simulation models fundamentally serve as tools for evaluating alternative scenarios, which necessitates the definition of quantifiable output variables. Interviewee R_e highlights that a supply chain simulation must generate measurable results, such as lead time, service level or production volume, in order to assess the performance of a given solution and provide answers to the questions posed. Similarly, interviewee Q_e stresses the need to explicitly define the KPIs prior to model development, recommending simulation practitioners to “list down the KPIs” that will be used to evaluate success. Interviewee T_e reinforces this perspective by emphasizing that a simulation model requires a defined set of evaluation metrics to differentiate between alternative system configurations.

Beyond defining KPIs, the experts also underline the necessity of aligning simulation outputs with the organization’s existing performance measurement systems to ensure relevance and credibility. Interviewee T_e emphasizes that model outputs should use the same terminology and structure as the metrics currently used within the organization, noting that aligning simulation dashboards with existing reporting formats helps “build the credibility of the simulation” and helps adoption. Interviewee Q_e similarly points out that demonstrating value through familiar and relevant metrics is important for securing organizational buy-in, particularly in early stages of a project.

Finally, the interviews indicate that KPIs should not only be treated as evaluation criteria but also as key design parameters for the simulation model itself. Interviewee T_e explains that the selection of target KPIs directly influences which aspects of the system require detailed modeling and which can be abstracted, for example through the use of black boxes. Similarly, interviewee Q_e suggests that defining the output KPIs helps maintain focus and prevents unnecessary model complexity, ensuring that the simulation remains aligned with its original objectives.

6 As-Is Analysis

This chapter presents the current state analysis of Scania's inbound logistics network in the context of supply base changes. Building on the empirical findings in Chapter 5, the literature presented in Chapter 4, and the research design outlined in Chapter 3, this section structures the subsequent analysis and the development of the Simulation Framework. This structure is guided by the conceptual modeling framework proposed by Robinson (2013) and the *Creating* phase framework (see Figure 7) introduced in Chapter 3. As established by Robinson (2013) in the simulation literature, this conceptual modeling process is highly iterative. Therefore, although the different stages are numbered, they do not represent a strictly chronological sequence, but instead they intend to illustrate the dynamic transition and continuous feedback between the As-Is Analysis, Gap Analysis, and the Simulation Framework. The compiled structure can be viewed in Figure 30.

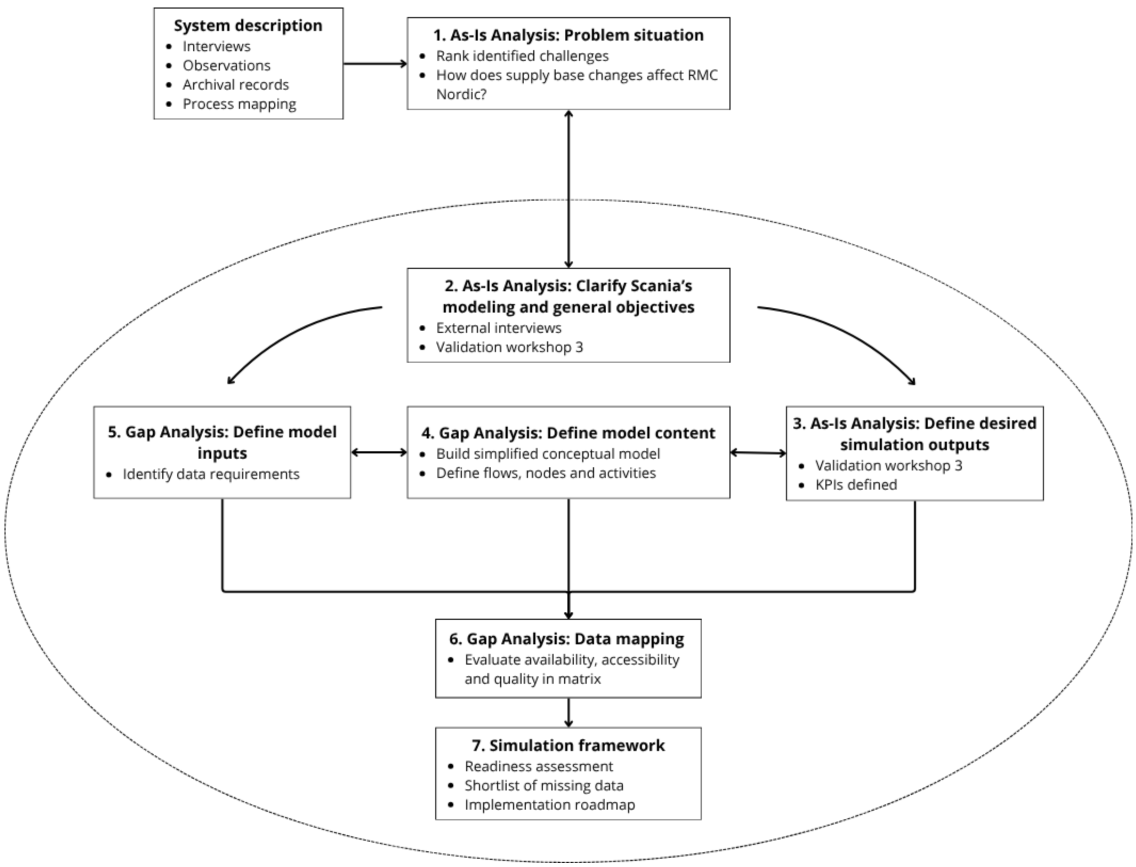

Figure 30: Structure of upcoming analysis steps and Simulation Framework, inspired by Robinson (2013)'s framework.

In Figure 30, it can be seen that the analysis starts by synthesizing the empirical findings from Chapter 5, which then serve as input to the three-step As-Is Analysis. The first step of the As-Is Analysis is initiated by clearly outlining the different challenges resulting from supply base changes within RMC Nordic's network. This is supported by the theoretical foundation, where it is recommended to follow a structured process when developing simulation models, with the first step being to clearly define the problem (Laguna and Marklund (2019); Kuhnt and Wenzel (2010); see Table 9 & Figure 15).

Based on the identified challenges, and in line with insights from the external interviews, the simulation project needs to be anchored in a clearly defined purpose, which constitutes the next step of the As-Is Analysis. This purpose is defined during the third validation workshop together with Scania. The final step of the As-Is Analysis consists of defining appropriate KPIs together with Scania during the same workshop. The purpose of this step aligns with van der Zee and van der Vorst (2005); Lundin and Norrman (2010), as establishing appropriate KPIs is crucial for evaluating the efficiency and effectiveness of modeled logistics networks and for comparing alternative system configurations. The reason why validation workshop 3 is the only one included in the analysis steps is due to the fact that the outcome of the workshop altered the course of the analysis and informed the following steps, while validation workshops 1, 2 and 4 generated no change of subsequent analytical steps. Since simulation models within SCND are typically used to compare the performance of different network configurations, aligning this step with existing performance measurements and ensuring that relevant KPIs are defined is fundamental for usability. These three steps of the As-Is Analysis are discussed in detail in the following sections.

6.1. Overall Challenges Connected to Supply Base Changes

The empirical findings indicate that changes in the supply base introduce a set of interconnected challenges that affect decision-making, operational performance, and simulation readiness within RMC Nordic. These challenges are derived from a cross-analysis of interviews across Logistics, Procurement, and external experts, as summarized in Table 5. While each challenge manifests in different parts of the organization, they are structurally linked and often reinforce one another. The following section presents eight identified challenges, combining empirical observations with analytical interpretation grounded in the theoretical framework.

Misalignment of Key Performance Indicators and Incentives

A recurring theme across interviews is the misalignment between Procurement's and Logistics' objectives. Interviewees from logistics functions (I_i, A_i, W_i, F_i & O_i) describe how procurement decisions are primarily driven by price, while logistics performance is evaluated based on total logistics cost and operational stability. Interviewees S_i, U_i & X_i from procurement confirm that cost reduction remains a dominant performance metric in sourcing decisions. This creates situations where supplier selections that are locally optimal for procurement generate downstream inefficiencies in transport planning, inventory, and factory feeding. Several interviewees (F_i, A_i, N_i, W_i, D_i & O_i) describe the need to "absorb" these consequences within Logistics' operations.

Reactive Rather Than Proactive Information Flow

Interviewees K_i, L_i, P_i, A_i, D_i & H_i across logistics roles consistently report that information regarding supplier changes is received late in the process. This results in logistics teams operating in a reactive mode, where transport solutions are designed under time pressure rather than through structured network design. Interviewees K_i & L_i mention "missing relations" with other functions and manual transport bookings, as well as compressed tendering processes due to receiving information late (Interviewee D_i). Several respondents also notes that communication between Procurement and Logistics is not always timely or structured, resulting in uncertainty and last-minute changes. For example, interviewees describe "last-minute surprises" when new suppliers are introduced or volumes change unexpectedly (Interviewees D_i, E_i, A_i). Procurement interviews (S_i & X_i) indicate that early logistics involvement is limited, reinforcing this pattern.

Increased System Fragility From Global Sourcing

Several interviewees (I_i, J_i,& G_i) highlight that shifts in the supply base toward overseas locations, particularly in Asia, introduce significant external factors and uncertainties that increase the complexity of logistics planning. Interviewees note that the expansion of the network's geographical footprint exposes it to unpredictable disruptions - such as geopolitical events, port congestion, and supplier failures - which force continuous network adjustments (Interviewees M_i, G_i, F_i, C_i S_i, & N_i). As a direct consequence of these supply base changes, Logistics faces increased variability in transport reliability and longer lead times. This fragility ultimately hinders stable and efficient operations for RMC Nordic, resulting in inflated safety buffers and an increased reliance on premium freight solutions (Interviewees E_i, F_i & N_i).

Hidden Operational Costs

Interviewees B_i, F_i, O_i, W_i describe how the true cost implications of supplier changes are not fully visible during sourcing decisions. Emergency shipments, overtime work and manual interventions are often required to maintain production continuity but are not captured in initial business case calculations, or followed-up properly after the integration of a certain supplier. Interviewees describe situations where procurement selects suppliers based on initial cost considerations, resulting in increased complexity or disruptions in logistics operations (Interviewees A_i, O_i, W_i & I_i). Interviewee W_i, Supplier Quality Engineer, explicitly mentions that previously, supplier choices have caused problems downstream for logistics and production and Interviewee A_i, Group Manager of LSM, mentions that there currently is a case where a badly rated supplier has been given a large contract, despite Logistics' warning signs regarding their internal logistics and the problems they might cause downstream. The problems generated from these supplier choices are then absorbed by Logistics' budgets, for example in the form of costly emergency shipments (Interviewee O_i). Since these hidden costs are practically invisible to decision-makers at Procurement, these problems continuously occur, creating the need for rigorous support teams in RMC Nordic (Interviewee B_i) that help resolve operational disruptions in the inbound supply chain. Procurement interviewees S_i & X_i acknowledge that these downstream costs are not systematically integrated into supplier evaluation processes, confirming RMC Nordic interviewees' views.

Poor Data Quality and Accessibility

Data-related challenges are highlighted by both operational and IT-focused interviewees O_i, P_i, K_i & L_i. Issues include inaccurate packaging data, missing transport parameters, and reliance on legacy systems requiring specialized knowledge. This limits the ability to model flows accurately and constrains the use of digital tools. Interviewee O_i specifically emphasizes the difficulty of extracting consistent data across systems.

Operational Bottlenecks in Factory Feeding

Interviewees N_i & F_i, responsible for inhouse logistics, describe how supply base changes affect arrival patterns and warehouse capacity utilization. Shifts in supplier geography alter delivery timing, leading to congestion and imbalances in staffing. Examples include evening peaks in inbound flows and situations where warehouses reach full capacity, requiring external storage solutions.

Article-Level Volume Volatility due to Modularity

Interviewees B_i, S_i, K_i & L_i highlight that Scania's modular production system introduces significant variability in part demand at the article level. While total volumes may be stable, individual components experience large fluctuations. This complicates transport planning and contract design, as carriers must account for uncertain volumes. This is described as a key limitation in establishing stable logistics flows.

Organizational Silos and Lack of end-to-end Responsibility

Across multiple interviews (E_i, I_i, J_i, P_i & S_i), a structural gap is identified in translating strategic decisions' effects into operational consequences. There is no clearly defined role responsible for ensuring that supply base changes - or other strategic decisions made later in the value chain - are evaluated from an end-to-end logistics perspective. Furthermore, no interviews mention formal processes for measuring downstream effects. A big contributing factor to this relates to the complexity of the network itself. The increasing number of suppliers, transport flows and product variants makes it difficult to maintain an overview of the system and identify optimal solutions. Interviewees describe that this complexity requires continuous coordination and adjustment across multiple functions (Interviewees S_i, J_i & E_i). A clear example of this challenge is identified in multiple interviews as the lack of alignment between Procurement and Logistics. Several respondents describe that supplier selection decisions are often made without sufficient consideration of logistics implications (Interviewees A_i, O_i & M_i). A clear example described are several situations where suppliers received bad supplier ratings from RMC Nordic but were nevertheless selected (Interviewees A_i, W_i, & F_i). This indicates that Procurement ultimately has the mandate for supplier selection decisions and can choose to prioritize other decision criteria over logistics-related concerns. Interviewee O_i reinforces this disconnect, states that there is "a lot of gap between RMC… and procurement".

This results in fragmented decision-making, where different functions act based on local information without a holistic understanding of system-wide effects. The organizational structure and distributed decision-making contribute to challenges in coordination. Responsibilities for different aspects of the logistics network are spread across multiple teams and functions, which can lead to inconsistencies in priorities and decision-making approaches (Interviewees S_i, H_i, W_i, O_i, N_i).

Supply Base Uncertainty

A fundamental challenge identified across the interviews is the high degree of uncertainty regarding the future configuration of the supply base. Logistics representatives describes a lack of proactive insights into future sourcing strategies, which severely hinders their ability to forecast transport costs, allocate capacity and strategically design the inbound network (Interviewees A_i, E_i, G_i, I_i & J_i).

From a procurement perspective, this uncertainty is tied to the inherent difficulty of establishing explicit, long-term sourcing plans at an article level (Interviewee S_i). While Procurement operates under clear overall strategic directives - such as the objective to achieve 85% localized sourcing value for the new China production unit, and a broader global strategy to increase sourcing from China up to a maximum 40% volume cap - the specific operational plan remain largely undefined (Interviewee S_i & X_i). Furthermore, the ongoing transition toward BEVs introduces additional unpredictability, as future component volumes and supplier selections remain highly dependent on fluctuating customer demand and market sentiment (Interviewee S_i & U_i).

Lack of Advanced Decision-Support Tools

The lack of advanced decision-support tools is another recurring theme. Interviewees describe that current planning relies heavily on spreadsheets and manual calculations, with limited capability to simulate the impact of supply base changes (Interviewees P_i, D_i, A_i, O_i, K_i, L_i & H_i). Furthermore, interviewee N_i explains that evaluations involving new suppliers frequently require manual calculations and extensive data handling, which is described as consuming unnecessary time and effort within the Flow Engineering function. This perspective discourages further sophistication of current cost calculation tools and rather advocates for a shift in the costs estimation process, making it difficult to evaluate alternative scenarios and understand system-wide effects.

6.1.1. Summarizing Challenges Into Three Main Problem Areas to Address

While the nine challenges above describe distinct aspects of the current state, they are not independent. Instead, they can be grouped into three overarching problem areas that capture the structural limitations of the current decision-making environment. Figure 31 shows how these three problem areas encompass the identified challenges.

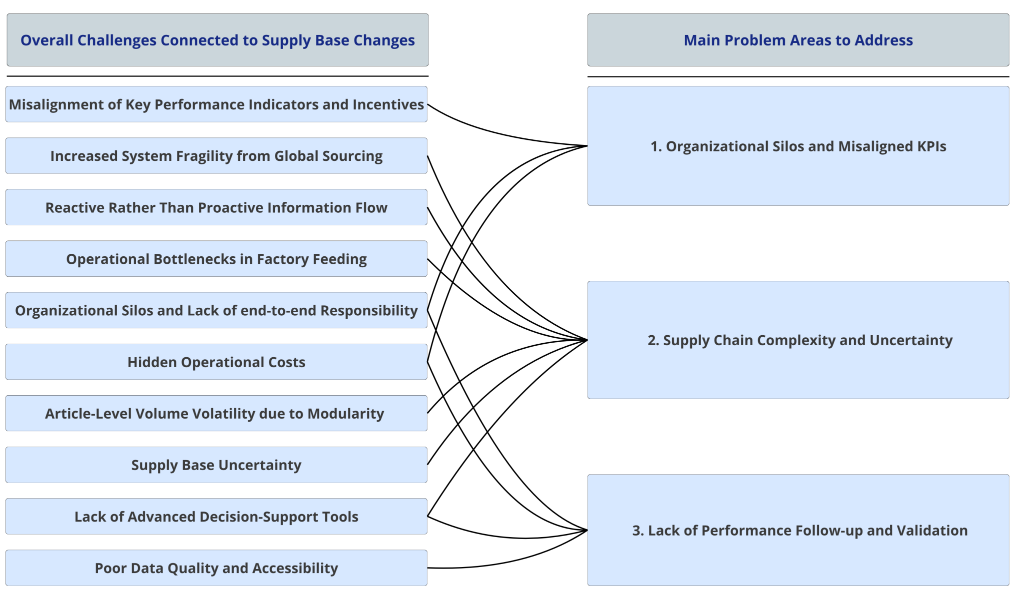

Figure 31: Schematic of underlying challenges per problem area

First, organizational silos and misaligned KPIs are prevalent due to the challenges arising from misalignment of KPIs and incentives, organizational silos and lacking end-to-end responsibility and hidden operational costs which obfuscate accurate measurement of functional performance. This problem area creates working conditions in RMC Nordics where local optimization dominates system-wide performance and where KPIs steer logistics and Procurement functions towards conflicting goals.

Second, supply chain complexity and uncertainty emerge as a consequence of increased global sourcing, high product modularity, supply base uncertainty and the lack of advance decision-support tools to handle this complexity and uncertainty. Rather than proactively designing the logistics network to mitigate these vulnerabilities, the compounding complexity forces the organization to adapt to changes only after they occur. This inevitably drives reactive decision-making practices, limits the ability to systematically evaluate alternatives and increases overall operational risk.

Third, lack of performance follow-up and validation is reflected in the organizational silos and lacking end-to-end responsibility which hinder accurate performance follow-up, hides operational costs and consequently clouds attempts of validating performance. The use of principle-driven calculation tools which are not measured on actual performance - and poor data quality and accessibility - further hinders accurate, systemic performance tracking. These limitations prevent the organization from learning from past decisions and improving future ones.

These three problem areas - *Organizational Silos and Misaligned KPIs*, *Supply Chain Complexity and Uncertainty* and *Lack of Performance Follow-Up and Validation* - are therefore identified as the most critical to address, as they represent root causes rather than symptoms. Addressing them is also directly linked to enabling simulation-based decision support, as outlined in Chapter 4. Specifically, simulation requires aligned objectives, proactive planning processes, and reliable data with feedback mechanisms. Without these conditions, the ability to implement and utilize simulation tools effectively remains limited. Table 10 presents the empirical findings connected to the summarized challenges in the form of specific quotes from the interviews, and correlates them with the theory discussed in Chapter 4.

Table 10: Synthesis of empirical findings and literature regarding supply base changes

EMPIRICAL FINDINGS	LITERATURE STUDY
Organizational Silos and Misaligned KPIs	
"We (Logistics) are working towards completely different goals in comparison to Procurement." (A_i)	Supply chain performance must be understood at a system level. Misalignment across functions can lead to conflicting actions (Chopra and Meindl, 2013).
"I think in general, we're struggling with understanding from each other what is important... for them (Procurement) logistics is just a side thing" (D_i)	Effective supply chains requires "systemic strategic coordination", rather than local optimization within different business functions (Mentzer et al., 2001).
"We are often not in symbiosis..." (F_i)	Alignment requires decision rights and performance measures to be designed to support system outcomes (Simatupang and Sridharan, 2005).

"What do our customers really need? Because we are convinced that a part of our customers does not need a 24-hour service level..." (E_i)	When supply chain process or -design is changed, investments must often be made in other positions and functions (Lundin and Norrman, 2010).
"...the cost of premium shipments is a huge cost which is not visible at procurement" (O_i)	While decisions regarding supply chain design are highly interdependent, it is a challenge to consider this interdependence (Dias and Ierapetritou, 2017).
"The other main challenge is sometimes the different targets also in between procurement and logistics." (M_i)	Every member in a supply chain tends to maximize their own interests. Optimal decisions may cause delivery delays (Wong et al., 2012).
"Even at procurement they also work in quite a lot, like in silos... Get some type of overarching level to create a holistic understanding." (I_i)	
"There doesn't really exist any such speaking partner on logistics... it is very, very impersonal between procurement and logistics today." (S_i)	
"Sometimes we need to make an exception from disqualifying them. Then we'll write a waiver... So we at logistics approve moving forward with a nomination we don't believe in..." (A_i)	
Supply Chain Complexity and Uncertainty	
"How will the China project affect volumes going forward... it is incredibly complex" (S_i)	Traditional supply chain models often fail since they frequently do not address uncertainties and imperfect information (Bellamy and Basole, 2013).
"Without insight into how our supply base will shift ... it is a huge challenge for us to forecast what we will have to pay for transports" (I_i)	Because decisions regarding supply chain design are highly interdependent, outcomes often do not meet expectations (Dias and Ierapetritou, 2017).
"...you might not know what it [change in activity] depends on , if it's because an article has been phased out or a supplier removed." (H_i)	A sequential or top-down decision-making approach often produces suboptimal or unpredictable outcomes (Dias and Ierapetritou, 2017).
"The disadvantage [with the modular system] is that it's half impossible to try to understand what the volume of an article will be" (S_i)	Information required for critical decisions is often collected and stored in different departments (Dias and Ierapetritou, 2017).
"Even if the product price is cheaper to source from China, the risk of taking it by sea and air is quite large..." (X_i)	Companies often struggle to optimize cross-functional processes due to their complexity and interdependency (Saisridhar et al., 2024).
"We have very little connection to exactly which markets they are out exploring... basically just a message to source more in China." (X_i)	While modular product designs offer significant advantages, they introduce severe product complexity that fragments demand (Norrman and Olhager, 2023).
"I see a very big risk when we have... production units in Europe and we choose to take our material from so far away." (A_i)	The structural complexity of a supply network, specifically its geographic spread, directly affects risk propagation (Lu and Shang, 2017).
"They have a case calculation in Excel where they are able to make comparisons... It's at the moment all in Excel" (D_i)	

Lack of Performance Follow-Up and Validation	
"We [Logistics] just plan, do, act and then there no check" (D_i)	Performance measurement is essential to verify that implemented decisions reached their goals (PDCA cycle) (Fleischmann et al., 1998).
"... there is no evaluation, no tracking at all to see if we in the end have made the right decision" (D_i)	To evaluate impact, organizations must utilize robust performance measurement systems providing feedback (Wong et al., 2012).
"We (Logistics) have sought some (KPIs) from management. Like what is actually expected from us?" (A_i)	Performance measurements fundamentally shape organizational behavior: *"what gets measured, gets managed"* (Christopher, 2016).
"The calculation is based on our actual volumes... It would have been an interesting thing to see [if things changed]." (H_i)	The lack of transparency and visibility across supply chains is the main obstacle to internal and external alignment (Wong et al., 2012).
"We get no indications or follow-up from logistics today on how did it turn out if one says after a year?" (X_i)	No stage of the supply chain learns from its actions over time because the consequences occur elsewhere (Chopra and Meindl, 2013).
"Let's say we went from five to four pickup days. It was not crystal clear and not easy to follow up." (N_i)	Learning can be engineered through *"joint check-act routines"* to understand the connection between process and performance (Nakano, 2020).

6.2. Blockers for Simulation-Based Decision Support

The previously mentioned structural issues of the problem areas demonstrate a clear operational vulnerability when RMC Nordic manages supply base changes. As stated by Stefanovic et al. (2009); Terzi and Cavalieri (2004), an inability to predict systemic consequences of sourcing decisions, highlights the limitations of traditional and static planning methods. This motivates the need for dynamic simulation-based tools. However, identifying the operational need for a simulation tool is not synonymous with having the organizational capability to implement it. As emphasized in the literature review, successfully developing a simulation model requires organizational and technical readiness, including clearly stated modeling objectives and rigorous data availability (Laguna and Marklund, 2019; Kuhnt and Wenzel, 2010). To make an informed and pragmatic decision about the objectives of the simulation model, an analysis of the potential blockers that could hinder effective implementation or -use of the simulation model is performed. Three main blockers are identified. Table 11 shows the three main blockers with corresponding interview quotes and theory to support the analysis.

Table 11: Synthesis of empirical findings and literature regarding simulation modeling at RMC Nordic

EMPIRICAL FINDINGS	LITERATURE STUDY
Undefined simulation objectives	

"If you have an open-ended set of questions, then you have to build a very comprehensive model that answer many questions, which is a recipe for disaster. Always start with clear objectives of the project." (T_e) *"There are so many functions involved, and a lot of uncertainty as well - which makes simulation hard"* (D_i) *"Ideally start modeling with a specific issue, using very specific outlined KPIs "* (Q_e) *"The most successful projects are those where you start with a rather small question that you build upon* (V_e)	According to Laguna and Marklund (2019), the very first and most critical step is to define exactly the problem that needs to be solved. The *Goal Setting* step in Kuhnt and Wenzel (2010)s informational acquisition process ensures that model complexity is kept to a minimum by focusing only on the specific KPIs desired. Robinson (2013) states that "poorly understood modeling objectives can lead to an overly complex model" and emphasizes that defining the model's outputs (KPIs) prior to building is essential to dictate the model's scope, level of detail, and necessary inputs. Modeling objectives drive all aspects of the model including the nature and scope of the model, validation and measure for success of the model (Chahal et al., 2013).
Limited cultural and technical experience	
"We have a lack of competence. We would need someone who actually drives that [simulation] question" (A_i) *"Simulation is completely foreign to us"* (M_i) *"Simulation for me, then we are talking about time events ... stochastic outcomes (with) 20 times the data complexity of network optimization"* (V_e) *"It depends very much on the company's ability to put effort into this ... if you are not willing to put in that time and resources, you will get nowhere"* (V_e) *"... these kind of things, we would need someone full time. Lot of analysis ... That doesn't happen with the existing resources I have"* (O_i)	Successful simulation adoption requires specialized technical skills and significant commitment of time and resources. For organizations lacking internal expertise, attempting to develop complex models in-house without dedicated funding and experienced analysts is highly risky and will likely compromise project objectives (Laguna and Marklund, 2019).
Data availability and quality	
"The data quality is usually crap... we still have quite a lot of manual processes to retrieve the data" (K_i & L_i) *"We also have a very scattered system knowledge with very much, like home-made and legacy systems... binding together data and being able to interpret data in a good way is not especially easy"* (I_i) *"... we don't have a data availability on a really easy manner"* (A_i) *"We have tried before ... but back then it didn't succeed because the data was not good enough ... So then what you simulate is scrap"* (D_i)	Information acquisition in the process of model building often takes up to one third of the total project effort (Kuhnt and Wenzel, 2010). Non-existence of data, lack of access to data sources and low-quality of collected data or corrupted data are perceived as main challenges for simulation modeling projects (Kuhnt and Wenzel, 2010). Experienced simulation analysts often consider data management to be the most challenging and dangerous aspect of simulation project and warns about missing the signs of the so called "Data Woes" (Laguna and Marklund, 2019).

6.3. Validation Workshop With Scania

Following the identification of the primary supply base problem areas and the assessment of potential simulation blockers, the next step of the As-Is Analysis is to bridge these empirical findings and theoretical insights with a tangible modeling strategy. As explained in the introduction of this chapter and outlined in Figure 30, the principles of Robinson (2013)'s conceptual modeling framework are applied to structure a validation workshop with key stakeholders at RMC Nordic. As established by Robinson (2013), conceptual modeling serves as the critical link between physical reality and the intended simulation architecture by navigating between the problem domain and the model domain. To transition from a complex real-world problem to a simplified system description, this validation workshop was held with key Scania stakeholders with the purpose of presenting the identified challenges and jointly define the problem domain more clearly.

During the initial workshop session, the identified problem areas and simulation blockers were presented from the empirical findings. It was explained that before any data collection or model building could occur, the conceptual model had to be firmly grounded in a specific "real-world" problem, as proposed by Robinson (2013); Laguna and Marklund (2019); Kuhnt and Wenzel (2010). The established simulation literature highlights *Goal Setting* as the most critical first step in a simulation project and the insights from the external simulation experts also confirms the necessity of having clearly defined objectives and KPIs with simulation projects. Based on this, three distinct "real-world" problem cases that could be subject to simulation modeling were presented during this workshop. The proposed alternatives were grounded in the empirical findings and the challenges identified in the previous steps. Table 12 outlines the operational relevance of the respective conceptual model alternatives and the specific problems they solve.

Table 12: Proposed "real-world" problem simulation cases presented to Scania.

WHY IT'S RELEVANT	WHAT PROBLEMS IT SOLVES
Option 1: ***Simulation of LACE (Landed Cost of Estimation)***	
• Current LACE calculations are static and time-consuming. • LACE outputs influences decisions made by procurement which affect the entire inbound logistics chain. • Possibility to pin-point where potential bottlenecks could occur in the logistics supply flow. • Clear KPI and limited scope.	• Captures complex interdependencies between divisions and natural randomness of variables. • Integrates risk assessment into the LACE calculations. • Allows decision-makers to see at which parts of the supply chain costs arise, enabling accurate cost allocations.
Option 2: ***Simulating lead times for supplier relocations***	
• Major relocations of suppliers to different continents will increase lead times in different functions. • Since point of gravity will change, certain flows may become overrepresented or obsolete. • Too many interdependencies to analytically model risks associated with increased lead times.	• Captures and showcases underlying risks associated with lead time increases. • Potential to groundedly guide TRATON consolidation initiatives.
Option 3: ***Mapping requirements for simulating multiple KPIs***	

• Focus is placed on capturing multiple variables over sophistically tracking a single variable.	• Enables the analysis of multiple KPIs to make decisions well-rounded.
• Possibility to compare several KPIs and their interdependencies.	• Avoids problems regarding data availability halting the short project deadline.
• Starts by tracking multiple KPIs in a simple way. Possibility to increase sophistication as simulation readiness matures in RMC Nordic	• Eliminates the risk of sub-optimization by allowing for well-rounded decisions based on the interdependencies of multiple KPIs, rather than isolated variables.

Rather than immediately selecting a case, the workshop focused on challenging the RMC Nordic stakeholders to critically reflect on their initial expectations for this master thesis project. By highlighting the consensus among both literature and external simulation experts that open-ended, loosely defined simulation models are a ”recipe for disaster” (Interviewee R_e), the stakeholders were pushed to define the fundamental underlying reason why they had identified simulation as a potential tool for RMC Nordic in the first place. To ensure a well-considered decision, the workshop was concluding by giving the stakeholders a few days to internally review the findings and evaluate the three proposed cases.

A follow-up validation workshop was subsequently held, and in this session, the Scania stakeholders presented their internal reflections regarding the empirical findings and the three proposed simulation cases. Through a joint evaluation, the third proposed alternative - *Mapping requirements for simulating multiple KPIs* - was selected, as it is best aligned with RMC Nordic's initial thesis expectations and provided a feasible scope given the organization's current simulation readiness. With the ”real-world” problem firmly established, the workshop concluded by explicitly defining the desired KPIs to be included in the conceptual model.

6.4. Define Desired Key Performance Indicators to simulate

The third and final step of the As-Is Analysis consists of establishing appropriate KPIs to include in the conceptual model. The KPIs dictate the necessary inputs, contents and outputs of the conceptual model and ensure that the simulation can effectively evaluate and compare the performance of alternative logistics network configurations in future use cases. RMC Nordic stakeholders concluded that attempting to simulate a highly detailed, specific operational process - such as mapping out every existing supplier, their exact lead times, total logistic costs and transport emissions - would contradict the primary goal of the project. As established in the simulation prerequisites literature, attempting to perfectly replicate a complex reality often leads to unmanageable models that are extremely difficult to construct, validate and use, especially in cases when data availability is poor (Robinson, 2013). Instead, RMC Nordic opted for the third proposed alternative, i.e. developing a conceptual model for a highly simplified logistics network to map the requirements for simulating multiple KPIs.

Rather than tracking a single isolated variable, the stakeholders explicitly requested the conceptual model to focus on the four specific KPIs that defined the thesis project initially: Total logistic costs, lead times, CO_2 emissions and stock levels. This selection strongly aligns with the discussed supply chain simulation literature. As noted by Kawasaki et al. (2015), modern low-carbon supply chains must be evaluated using multi-critera decisions that balance lead times, costs and CO_2 emissions, especially when sourcing from geographically dispersed suppliers. Furthermore, incorporating these three specific metrics allows the conceptual model to capture the inherent structural trade-offs of logistics network design, such as the balance between the economies of scale achieved through transport consolidation (lowering costs and emissions) and the resulting impact on delivery speed (increased lead times) (Keramydas et al., 2017).

To accomplish this without being hindered by the data quality issues and scattered legacy systems identified earlier in the As-Is Analysis, the proposed Simulation Framework will be based on a simplified, illustrative scenario. This abstracted system description will feature a fictive, limited number of suppliers, cross-dock relations and a few generalized transport flows. This approach is heavily supported by the conceptual modeling literature, which emphasizes that simpler models are highly preferred because they are faster to develop, require less data and offer results that are easier to interpret (Robinson, 2013). The conceptual model that will enable the desired KPIs as outputs will be presented in the following chapter and a summary of the desired KPIs to simulate can be found in Table 13 below.

Table 13: Desired KPIs to simulate

KPI	**Unit**
Total logistics cost	SEK
Lead times	Hours (h)
CO_2 emissions	Tonnes
Stock levels	# of pallets

7 Gap Analysis

As illustrated Figure 30, the subsequent analysis step following the As-Is Analysis is the Gap Analysis. To perform the Gap Analysis - which aims to identify the gaps that exist in the current state and how to bridge these gaps - a desired state is first formulated. This aligns with Holmström et al. (2009)'s "Means-End Analysis" methodology which takes the current state and the desired state into account to identify the gaps which are subsequently analyzed. The Gap Analysis is designed to achieve this through three sequential steps outlined in the analytical framework:

1. **Build conceptual model:** Initially, a simple, conceptual model is developed to be simulated. This abstraction represents the desired state of the simulation architecture.
2. **Identify data requirements:** Based on this conceptual model, the previously defined desired KPIs are used to systematically derived the exact data that needs to be available to correctly model the performance of the KPIs.
3. **Data availability mapping:** Finally, the current data availability in the archival records at Scania is mapped to see what data is available, its quality and what data is critically missing.

Based on the results of the data availability mapping, the critical data gaps are explicitly identified and the reasoning behind the necessary modeling assumptions is presented. These insights resolve the Gap Analysis before the Simulation Framework is presented in the next chapter.

7.1. Conceptual Model

Since the artifact created in this thesis is a simulation readiness framework rather than a finalized simulation model, the conceptual model that is used can be quite simple. In accordance with the literature study and the interviews, the model is deliberately made simple so as not to make the Simulation Framework too heavy and hard to digest for the reader and the case company. The conceptual model will therefore only consist of three suppliers, one cross-dock and one production unit. A schematic of the conceptual model along with the informational structure can be found in Figure 32.

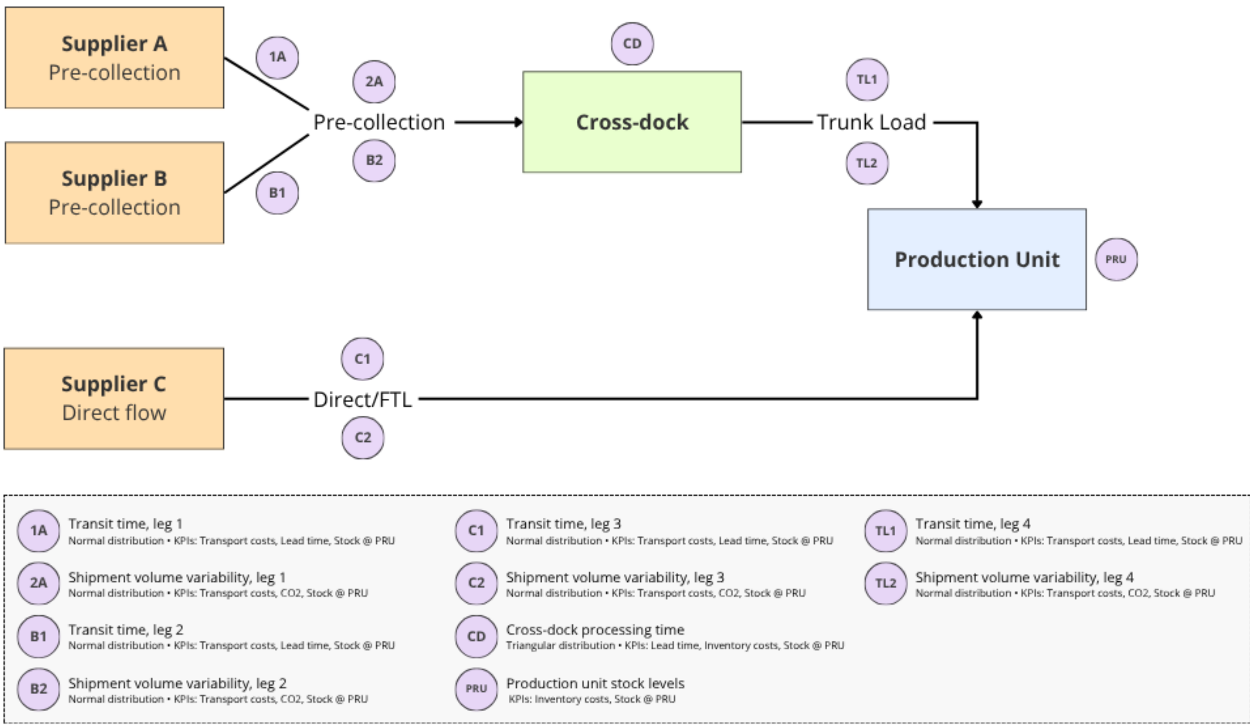

Figure 32: Conceptual schematic of the network to be modeled in the Simulation Framework

Although the model is very simple compared to RMC Nordic's actual logistics network, the framework is still useful as the process to model the conceptual network can be replicated for all additional suppliers, cross-docks, PRUs and routes to eventually cover the entire network. The Simulation Framework outlines the necessary steps to be able to model a logistics network by using the conceptual modeling as an example for how to model the entire network. The usefulness of the conceptual model and the Simulation Framework will be expanded in Chapter 9.2.

As established in the simulation literature, a simulation model is fundamentally characterized by its chosen simulation paradigm. For this study, the conceptual model relies on DES. While SD evaluates continuous, aggregated policy effects and ABS focuses on the decentralized behavior of autonomous actors, DES is uniquely suited to evaluate physical material flows and operational variables in sequential systems (Laguna and Marklund, 2019). By representing RMC Nordic's inbound logistics network as a system of activities and buffers, DES tracks the movement of individual flow units through discrete state changes over time. This event-driven logic provides the exact mechanism required to execute and evaluate operational decisions within a logistics network.

7.1.1. Modeling Objectives & Defined Key Performance Indicators

The objective of the conceptual model is to assess Scania's simulation readiness by defining its intended simulation outputs around the performance of four key KPIs:

1. Total logistics costs

2. Lead times

3. CO_2 emissions

4. Stock levels

To ensure consistency when evaluating the defined KPIs, it is important to note that the conceptual model relies on a standardized ”flow unit” that functions as the common transient entity that flows through the model's activities and nodes (Laguna and Marklund, 2019). The specific definition and practical characteristics of this flow unit within the context of Scania's network will be elaborated further in the *Model contents* (7.1.2) section.

To be able to simulate the performance of these KPIs, they need to be correctly modeled in order for the simulation model to produce an output of each KPI. In accordance with Interviewee T_e's recommendation, a simulation model should take one level deeper than the desired outputs in consideration to be able to derive the reason for changes in the KPIs. Therefore, the subcomponents of each KPI needs to be understood and recorded in the model. The following sections therefore explain each KPI and their respective subcomponents.

Total Logistics Costs

The total logistics costs comprise three different categories of logistics costs. Firstly, there's the cost for transporting the goods. Secondly, the inventory holding costs need to be considered and finally the processing costs. See Figure 33 for a full breakdown of how total logistics costs will be calculated in the model.

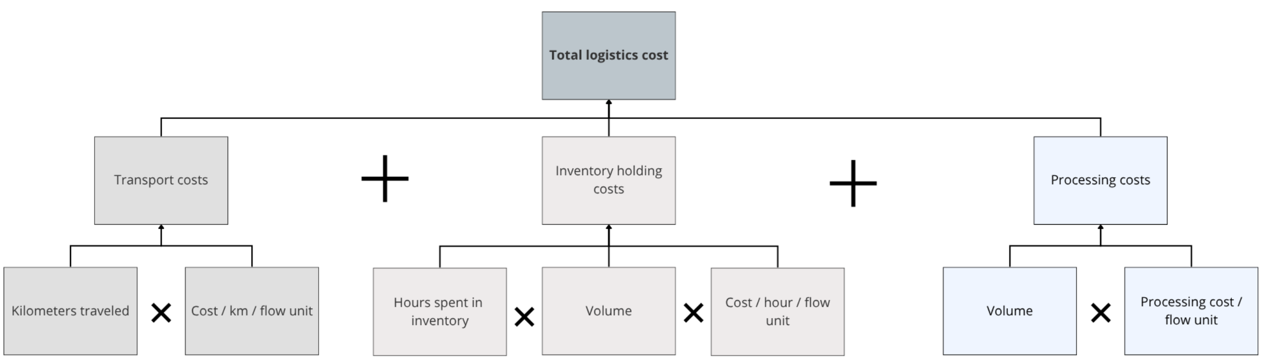

Figure 33: How the total logistics cost is calculated in the proposed conceptual model

As can be seen in Figure 33, the transport costs are calculated by multiplying the number of kilometers that the shipment has traveled with the cost per kilometer driven per defined flow unit. While this formulation is structurally simple, the cost per kilometer is not constant across flows. It is instead determined by the specific transport setup for each tendered route. Variations can arise from several factors, including the geographical characteristics of the route, administrative requirements such as border crossings and customs handling and other contractual conditions of the transport provider. In addition, the cost structure is influenced by the type of vehicle deployed, as well as the energy type used (e.g., diesel, electricity or alternative fuels) which directly affects operating costs. Consequently, the model assigns a flow-specific cost per kilometer based on the tendered transport configuration of the selected flow, rather than assuming a uniform rate across the network.

The inventory holding costs are calculated by multiplying the time that a shipment spends in inventory by its volume and the corresponding hourly holding cost per flow unit. In the conceptual model, inventory occurs at multiple points in the network. Firstly, inventory accumulates at the cross-dock, both prior to processing (when shipments are waiting to be unloaded) and after processing (when shipments are waiting to be consolidated into outbound loads). Secondly, inventory is present at the downstream logistics center or PRU, where shipments are buffered before being fed into the production process. By capturing inventory across these nodes, the model accounts for both temporary handling-related storage and more structural buffering required to ensure continuity in production.

Lastly, the processing costs are calculated by multiplying the time required to process a shipment with the processing cost per hour per flow unit. In this context, processing encompasses several activities along the inbound flow. These include physical handling operations, and sorting or consolidation activities performed at the cross-dock. By aggregating these activities into a time-based cost component, the model captures the operational effort required to move shipments through the system, independent of transport and storage considerations.

Lead Times

As illustrated in Figure 34, the total lead time is defined as the cumulative time elapsed from when components are ready at the supplier until they are available at the PRU. Rather than treating lead time as a single aggregated measure, the model decomposes it into a sequence of time-based sub-components that reflect the different stages of the inbound logistics process.

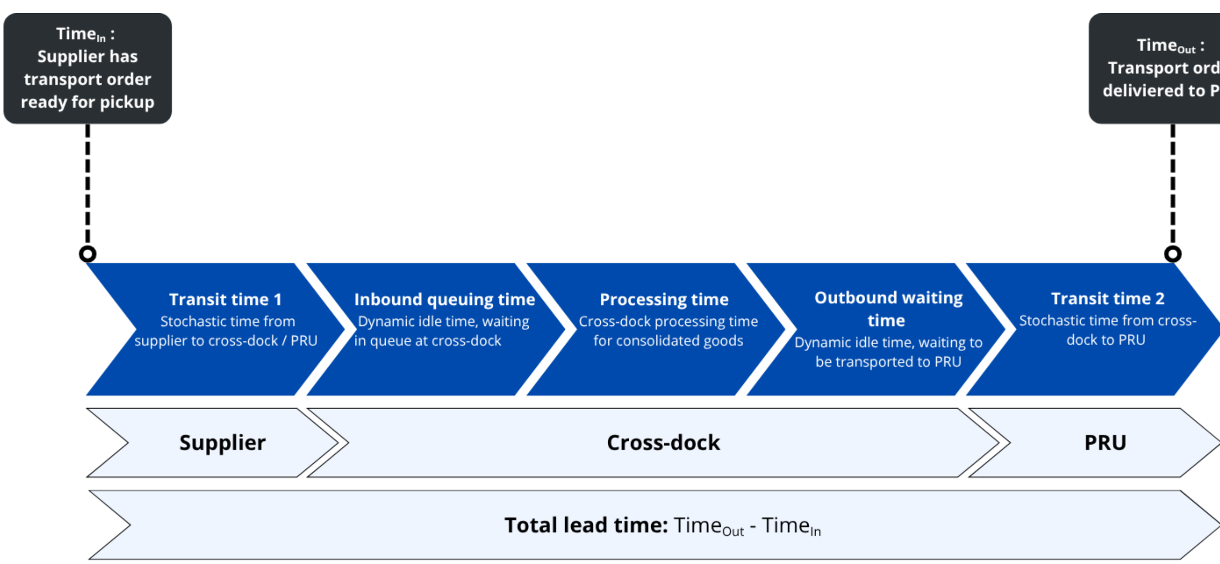

Figure 34: The subcomponents of the total lead time from supplier pickup to PRU

The first component is the transit time from the supplier, representing the time that elapses between when components are ready for dispatch and when they are actually delivered to the defined destination, i.e either to a cross-dock through a pre-collection flow or through a direct flow to a PRU. This component captures the physical movement of goods and is influenced by stochastic factors such as loading time and transport time.

In the case of pre-collection flows and upon arrival at the cross-dock, the shipment may experience a holding time before processing, reflecting queuing effects due to capacity constraints or synchronization requirements. This is followed by the cross-dock processing time, during which the shipment is unloaded, sorted and prepared for onward transportation. After sorting, an additional holding time may occur while the shipment waits to be consolidated into an outbound load. The next stage is the transport time from the cross-dock to the PRU.

By explicitly modeling each of these subcomponents, the simulation captures both transport-related delays and time spent in buffers throughout the system. This enables the identification of where lead time is accumulated within the network and allows for a more granular analysis of how changes in the supply base or logistics configuration impact the overall lead time. Simultaneously, the model intentionally excludes minor time events that are complex to model and require highly granular data.

CO_2 Emissions

As for the current Case Calculations routine, the emissions KPI is intended to be measured in CO_2e. The KPI is designed to dynamically evaluate the environmental impact of the inbound logistics network by capturing how fluctuating volumes and vehicle fill rates affect fuel consumption. The conceptual model evaluates emissions by embedding the mathematical logic of the external calculation tool Proxio directly into the simulation's event structure. Static parameters are predefined for each transport leg and assigned vehicle type, include the route distance, the vehicle's maximum weight capacity, the specific emission factor of the fuel used and the baseline fuel consumption for both an empty and a fully loaded truck.

To calculate the emissions dynamically in the conceptual model, the mathematical formulas from Proxio are adapted to trigger only when a vehicle is dispatched on a specific route. The dispatch event for a specific transport leg triggers the calculation of the simulated load. To apply the 60% minimum fill rate rule for CO_2e calculations, the simulated fill rate (FR_{sim}) for the trip is defined as:

$$FR_{sim} = max(0.60, \frac{Q_{sim} \cdot W_{unit}}{W_{max}}) \tag{7.1}$$

Where:

- Q_{sim} = The discrete quantity of flow units loaded on the truck during the dispatch event.
- W_{unit} = The static average weight per standard shipment unit (*kg*).
- W_{max} = The static maximum wight capacity of the assigned vehicle type (*kg*).

The specific fuel consumption for the loaded leg of the trip (FC_{loaded}) is calculated by scaling the consumption proportionally to the simulated fill rate:

$$FC_{loaded} = FC_{empty} + (FC_{full} - FC_{empty}) \cdot FR_{sim} \quad (7.2)$$

Where:

- FC_{loaded} = The dynamic fuel consumption of the truck for the loaded trip (*liters/km*)
- FC_{empty} = The static baseline fuel consumption of the specific truck when driving completely empty (*liters/km*).
- FC_{full} = The static fuel consumption of the specific truck when driving at maximum weight capacity (*liters/km*).

To account for the total environmental impact of a dispatched truck event, including the empty running factor, the total emissions for the single trip (E_{trip}) are calculated as:

$$E_{trip} = [(d_{loaded} \cdot FC_{loaded}) + (d_{empty} \cdot FC_{empty})] \cdot EF \quad (7.3)$$

Where:

- E_{trip} = The total CO_2e emissions generated by this specific vehicle dispatch event (CO_2e [kg]).
- d_{loaded} = The static distance of the specific transport leg (*km*)
- d_{empty} = The static empty running distance (*km*), typically calculated as a percentage of d_{loaded} (17%).
- EF = The static emission factor dictated by the vehicle's fuel type (*kg* CO_2e / *liter*)

The overall network CO_2 Emissions KPI is calculated by continuously accumulating E_{trip} values for all N truck trips triggered over the entire simulation horizon T:

$$Total\ System\ CO_2e = \sum_{k=1}^{N} = E_{trip,k} \quad (7.4)$$

Stock Levels

The Stock Level KPI is designed to model how the inventory levels at the destination node (PRU) are affected by changes by the upstream supply base. Because of the delimited scope of this thesis, the conceptual model is strictly delimited to the inbound logistics network and intentionally excludes downstream end-customer demand. Therefore, this KPI is not calculated using traditional retail stock-out models, instead it is evaluated through the lens of process dynamics and the steady-state equilibrium approach, as discussed by Fleischmann et al. (1998) and Laguna and Marklund (2019) in Chapter 4.3.3.3.

Fundamentally, the stock levels are modeled as dynamic accumulation buffers. In the conceptual simulation model, this KPI is calculated using a recursive relationship where the inventory at any given time is determined by the inventory level at the previous time step, plus the quantity of flow units entering the node, minus the quantity of items absorbed by the PRU. Let Q_t be the stock level (measured in the defined flow unit) at the PRU at the end of time interval *t*. This variable is defined by the following recursive formula:

$$Q_t = Q_{t-1} + e_t - u_t \tag{7.5}$$

Where $Q_{t\text{-}1}$ is the stock level at the previous time step, Q_0 represent the initial starting inventory available at time 0 (which serves as the initial safety stock). e_t is the quantity of flow units arriving at the PRU during time interval *t*. In the simulation, this variable is highly stochastic and discrete, driven by the arrival of consolidated truckloads and transport delays from the upstream network. u_t is the quantity of flow units "consumed" by the PRU during time interval *t*. To implement this calculation without explicit PRU demand data, the model relies on three foundational modeling assumptions:

- **The continuity assumption:** This absorption occurs in a regular interval over time.
- **The steady-state assumption:** The PRU node absorbs the incoming flow units at a given, constant rate. Therefore, the stochastic consumption variable u_t is replaced by a constant scalar, (q (i.e., $u_t = q$ for all *t*).
- **The equilibrium assumption:** The overall rate at which products are made available at the suppliers is strictly equal to the constant rate q at which they are demanded at the destination.

By applying these assumptions, the recursive inventory calculation at the PRU simplifies to:

$$Q_t = Q_{t-1} + e_t - q \tag{7.6}$$

In practice, this means the simulation will calculate the stock level KPI by continuously "using up" the PRU's inventory buffer at a steady, constant outflow rate that perfectly matches the historical average of the suppliers output. Meanwhile, the inflow into the PRU buffer will be variable and discrete, driven by the stochastic arrivals of consolidated truckloads and transport delays from the upstream network. By calculating the stock level under this equilibrium, the simulation model successfully isolates the system's internal logistical behavior. Since the average supply and demand are perfectly matched over the long run, any physical queue that accumulates or is "used up" at the PRU during the simulation is mathematically guaranteed to be the direct result of logistical variability - such as stochastic transportation lead times or cross-dock handling delays.

Ultimately, tracking this dynamic buffer allows the simulation to evaluate how a fictitious stock level of flow units is affected by different upstream logistical scenarios. The initial stock level is derived by defining an initial stock level (Q_0) at the PRU required at time zero to ensure that the stock level never drops below zero if a delayed replenishment delivery arrives for example.

Implementation Logic of Key Performance Indicator Outputs

The simulation generates its outputs by tracking the standardized flow unit (the pallet) as it travels through this specific network of nodes and activities. The defined KPIs are directly tied to the flow unit's progression through the simulation as follows:

- **Total Logistics Cost:** Costs are accumulated as the flow unit triggers specific activities and passes through nodes. Transport activities for direct flows and pre-collections trigger calculations based on regional rate tables. When a unit passes through a cross-dock node, it incurs a specific handling cost per unit. Finally, the consolidated transport activity from the cross-dock to the PRU triggers the fixed trunk load costs.
- **CO2 Emissions:** This KPI is tied to the capacity triggers within the nodes and the execution of transport activities. Whenever the accumulation of flow units at a supplier or cross-dock node triggers a vehicle dispatch, the simulation dynamically adds the pre-calculated, static CO2e trip parameter to the system's total emissions accumulator.
- **Stock Levels:** This KPI is measured exclusively at the PRU node. By evaluating the PRU as an accumulation buffer, the simulation software tracks the exact queue length of flow units residing at this final node at any given time. The stock level naturally rises as transport activities deliver discrete batches of units, and falls according to the PRU node's steady-state consumption activity.
- **Lead Times:** Lead times are recorded when the flow unit is in an activity or a buffer, starting from the time the flow unit is created in the supplier node to the time when the flow unit exits through a PRU node. The software calculates the sum of the disaggregated lead times to the total lead time and outputs all lead times.

7.1.2. Model Contents

This section defines the specific structural and operational components that make up the conceptual model. Drawing upon the business process definition established by Laguna and Marklund (2019), the model's architecture is broken down into three distinct elements. In the following subsections, the standardized ”flow unit” introduced previously is explicitly defined in the context of RMC Nordic's inbound network. This is followed by a detailed specification of the network of nodes and activities, the transport flows and resources, and the underlying information structure required to accurately simulate the logistics flows.

Flow Units

In the context of process modeling and DES, a flow unit is defined as a ”transient entity” or a ”job” that continuously moves through the various activities and buffers of a system before finally exiting as a finished output. The motivation for establishing a clear and standardized flow unit is fundamentally rooted in how DES's function. DES models describe how a system evolves over time by tracking these specific flow units as they move through the system and trigger state changes. Consequently, having a strictly defined flow unit is critical because it has an immediate and direct impact on how the model evaluates process capacity and investment levels. While the exact characteristics and identities of flow units can vary significantly depending on the specific process, the chosen standardized flow unit for this conceptual model is a pallet.

Furthermore, utilizing a standardized unit like a pallet is essential for interacting with the network's activities and buffers. Because the inbound logistics network involves transporting and consolidating a highly variable mix of modular components, standardizing the historical volume data into uniform discrete units allows the simulation to measure the system's overall flow rate defined as the number of flow units passing through the process per unit of time. This uniform measurement is what enables the simulation to accurately and consistently calculate how much physical capacity is being utilized in a transport vehicle or a cross-dock at any given time, regardless of the underlying components being moved.

Network of Nodes and Activities

As mentioned in Chapter 4.3.1, in DES, a business process is fundamentally defined as a network of connected activities and buffers with well-defined boundaries and precedence relationships, through which flow units pass. To simulate RMC Nordic's inbound logistics, the physical supply chain infrastructure is abstracted into these specific modeling elements. The conceptual schematic of the network (as illustrated previously in Figure 32) visualizes how the physical supply chain is translated into a sequence of simulation events, where the physical facilities act as the nodes and the transportation and handling processes act as the activities. The Nodes in the conceptual model, i.e., the physical locations in the supply chain, serve as the structural nodes where flow units are generated, stored, processed or consumed. In a simulation environment, these nodes primarily function as buffers where flow units experience planned or unplanned delays:

- **Supplier Nodes (Origins):** These nodes serve as the entry points of the simulation where the standard flow units (pallets) are generated based on stochastic historical volume distributions.
- **Cross-Dock Nodes (Intermediate Buffers):** For indirect flows, the cross-dock acts as an accumulation buffer. Flow units arriving from various suppliers wait at this node until a specific operational rule is met (e.g., reaching an 80% vehicle fill rate target). This represents a planned delay where the units are batched before continuing their routing.
- **Production Unit Node (Destination):** The PRUs act as the exit points in the inbound network scope. As established by the steady-state equilibrium approach, this node functions as a dynamic accumulation buffer where arriving shipments queue up and are continuously depleted by a constant consumption rate.

Activities represent the actual work being performed on the flow units, serving as the links that move the units between the nodes.

- **Transport Activities:** These activities simulate the physical movement of goods (e.g., direct shipments, pre-collections, and consolidated trunk loads). In the simulation, executing a transport activity involves pairing flow units with a transport resource and then delaying the flow unit by a stochastic transit time before it reaches the next node.

- **Handling Activities:** These activities represent the physical unloading, sorting and reloading processes at the cross-dock nodes before the units are batched into outgoing transport activities.

Transport Flows and Resources

To effectively evaluate and compare the performance of different network configurations, the conceptual model must define the specific transport flows and the physical resources required to execute them. In the simulation, the routing of the standardized flow units is abstracted into two primary flow archetypes that operate in parallel, allowing for direct comparative scenario analysis.

The first configuration is Flow Archetype A (Direct Flow), which represents the physical movement of goods directly from the Supplier node to the PRU. Depending on the stochastic volume generated and predefined capacity thresholds, this activity is executed as either a FTL or a LTL dispatch. The second configuration, Flow Archetype B (Cross-dock Flow), models an indirect routing strategy designed to consolidate shipments. This archetype is split into two distinct operational legs: an initial pre-collection leg from the Supplier to an intermediate Cross-dock - frequently performed as a milk run or an LTL transport to aggregate smaller volumes - and a subsequent consolidated trunk load (FTL) leg, transporting the batched units from the Cross-dock to the final PRU.

Executing these flows within the simulation relies on specific transport resources and well-defined routing parameters. Because the road truck is the dominant transport mode within the RMC Nordic network, it serves as the main resource object assigned to the network. To accurately calculate the system's costs, emissions, and operational constraints, each truck is defined by a distinct set of vehicle properties. These properties include the selected transport mode, the specific type of trailer (which dictates its maximum volume and weight capacity), the type of fuel utilized and its baseline fuel consumption profile.

Furthermore, the physical movement of these vehicles is governed by the specific properties of each transport leg. Each individual transport leg in the network is strictly defined by its static route distance, the specific vehicle assigned to execute the route, the scheduled pick-up frequency, and the resulting stochastic lead time it takes to complete the transit. By embedding these granular properties into the resources and transport legs, the model dynamically captures how changes between the two flow archetypes impact the overall network efficiency, lead times, and environmental footprint.

7.1.3. Model Assumptions and Simplifications

The conceptual model incorporates deliberate assumptions and simplifications, guided by both the simulation literature and findings from external expert interviews. Table 14 and 15 provide a summary of the assumptions and simplifications respectively. These choices are designed to reduce the overall complexity of the framework, thereby facilitating the future implementation of an operational simulation model for RMC Nordic. Theoretically, model assumptions are introduced to address uncertainties about the real world and simplifications are intentional abstractions made to enable more rapid model development, reduce data requirements and improve model transparency. Furthermore, these implications ensure the model is tailored for comparative scenario analysis rather than exact predictive analysis. This aligns with defined simulation purpose for this thesis project, i.e. provide indications of how supply base changes will affect the inbound logistics network compared to the current baseline, illustrating the relative impact of varying network inputs.

Assumptions

Table 14: Conceptual model assumptions.

Category/Parameter	**Description**
Steady-state equilibrium	Supply rate equals PRU demand rate on average.
Constant PRU consumption	Demand-side variability does not exist within the model scope.
Pallet homogeneity	All pallets functionally equivalent regardless of their physical contents.
Stochastic representation of reality	Historical data distribution accurately reflect the future behavior of the system, meaning that stochastic volume generation and transit time delays will mirror real-world logistical variability.
Parameter stability	Model parameters (e.g., cost/km, leg distances, emission factors) are assumed to be stable over the simulation horizon.
Unconstrained vehicle resources	The model assumes infinite availability of vehicles available for carrier transport to reduce unnecessary model complexity and isolate the impact of supply base variability.

Simplifications

Table 15: Conceptual model simplifications.

Category/Parameter	**Description**
Delimited network scope	Rather than simulating the entire RMC Nordic network, the physical structure is abstracted to three representative supplier nodes, one cross-dock, and one PRU. Furthermore, downstream customer demand is excluded from the system boundaries. This deliberate reduction of structural and dynamic complexity isolates the inbound logistics behavior, avoiding operational noise and allowing for clear model validation before scaling to a full network.
Excluded transport modes	Overseas and multi-modal flows are excluded from the model. Truck transport is defined as the only transport mode, to simplify the identification of data requirements. Additional transport modes can easily be configured into to the model as all vehicles are represented as individual resource objects with standardized attributes, meaning the underlying simulation logic remains consistent across all modes.
Excluded components types	Flows including sequence parts are excluded from the scope and only batch parts are considered due to inherent data unavailability and complexity of sequence orders.
Simplified KPI calculations	All simulated KPIs are intentionally simplified compared to Scania's current routines and adapted to the standardized flow unit. In alignment with recommendations from the external expert interviews, this reduces model complexity to facilitate implementation, establishing a functional baseline that be further developed with additional complexity in the future if needed.

Standardized flow unit	To fulfill the DES requisite of tracking discrete items through a system, highly heterogeneous components are abstracted to a single standardized flow unit in the form of a uniform pallet. Although this necessitates rough data conversions of volume and weight data into discrete units, it significantly reduces the model complexity by standardizing the computation of system flow rates, vehicle capacity utilization and node processing times. In future models, this baseline can be refined by assigning unique entity attributes (e.g., exact dimensions and weights) to multiple flow units to represent physical reality more accurately.

7.2. Identify Data Requirements

As established in the conceptual model (Figure 32), the simulation model will represent the system through a set of suppliers, cross-docks, production units and transport flows. Each of these components must be described through a defined set of attributes that capture both their structural characteristics and their role in the material flow. The purpose of this section is therefore to specify the input data required to represent these components in the simulation and to clarify why each input data type is necessary. The identification of data requirements follows the principle that a simulation model must accurately represent both the physical structure of the network and the flow dynamics between its nodes. The data requirements are presented in the order of the four model components. The following subsections outline the required data types for each component.

7.2.1. Suppliers

Suppliers make up the origin points of all inbound material flows and are therefore fundamental in defining both the structure and dynamics of the logistics network. To represent suppliers in the simulation model, four key data attributes have been identified which can be found in Table 16 below.

Table 16: Required data types to model suppliers

Data Type	Description
Supplier location	The geographical location of each supplier is required to position the node within the network. This data enables the calculation of transport distances and routing between suppliers, cross-docks and production units.
Order weight	Order weight defines the mass of shipments originating from each supplier. This attribute is necessary for modeling transport utilization, as weight constraints directly affect vehicle capacity usage, consolidation decisions and transport cost calculations.
Order volume	Order volume captures the physical space required for shipments. Since transport planning is constrained by both weight and volume, this data is required to realistically model loading limitations and consolidation opportunities.

Order destination	The destination specifies the receiving node, typically a production unit or an intermediate node such as a cross-dock. This data is critical for defining network links and material flow paths within the simulation.

7.2.2. Cross-docks

Cross-docks represent intermediate nodes in the inbound logistics network where material flows are consolidated, sorted and redirected toward their final destinations. In the simulation model, cross-docks shape the flow structures, influencing both transport efficiency and lead times. To accurately capture their function, four key data attributes have been identified which can be found in Table 17.

Table 17: Required data types to model cross-docks.

Data Type	**Description**
Cross-dock location	The geographical location of each cross-dock is required to position it within the network structure. This enables the simulation to define feasible routing alternatives between suppliers, cross-docks and production units, while also supporting distance and lead time calculations.
Sorting capacity	Sorting capacity defines the maximum throughput that a cross-dock can handle. This attribute is required to model operational constraints, as limited capacity may lead to congestion, queuing or the need for alternative routing decisions.
Sorting speed	Sorting speed describes the rate at which goods are processed within the cross-dock. This data is necessary to model handling times and contributes directly to the total lead time of shipments moving through the network.
Processing costs	Processing costs represent the cost incurred for handling goods at the cross-dock, typically expressed per pallet. This attribute is required to evaluate the economic impact of different network configurations, such as direct shipments versus consolidated flows through cross-docks.

7.2.3. Production Units

Production units represent the final receiving nodes in the inbound logistics network, where materials are consumed in the manufacturing process. Within the simulation model, they define the demand side of the system and thereby act as the primary drivers of material flows. To represent production units, two key data attributes have been identified and can be found in Table 18 below.

Table 18: Required data types related to production units.

Data Type	Description
PRU location	The geographical location of each production unit is required to position demand nodes within the network. This enables the simulation to determine transport distances and routing alternatives from suppliers, either directly or via cross-docks. The location data is therefore essential for calculating lead times, transport costs and emissions, as well as for evaluating different network configurations.
Demand	Demand specifies the required inflow of materials to each production unit over a given time period. This attribute is fundamental for generating flow volumes within the simulation, as it determines the quantity of goods that must be transported through the network. By defining demand at each production unit, the model can simulate how material flows are allocated across suppliers, cross-docks and transport resources, and assess the system's ability to meet required service levels.

7.2.4. Transport flows

Transports represent the connecting elements of the inbound logistics network, enabling the physical movement of goods between suppliers, cross-docks and production units. In the simulation model, transports are not only responsible for linking nodes, but also for capturing the operational and economic dynamics of the system. To accurately represent transport activities, thirteen data types have been identified and are presented in Table 19 below.

Table 19: Required data types to model transport flows.

Data Type	Description & Motivation
Pick-up location	The pick-up location defines the origin node of a transport movement, typically a supplier or cross-dock. This attribute is required to establish the starting point of each transport leg within the network.
Drop-off location	The drop-off location specifies the destination node of the transport, such as a cross-dock or production unit. Together with the pick-up location, this defines the network links and enables routing of flows.
Loading- & unloading time	Loading and unloading times represent the time required to handle goods at the origin and destination nodes. This data is necessary to model operational delays and contributes to the total lead time of each shipment.
Vehicle fuel type	The fuel type is required to differentiate between transport modes in terms of both cost structure and environmental impact. This attribute enables the simulation of emissions and supports the measurement of sustainability-related performance.
Vehicle fuel consumption	Fuel consumption defines the amount of fuel used per distance unit. This data is required to calculate emissions and transport costs.
Vehicle payload constraints	Payload constraints define the maximum allowable weight per vehicle. This attribute is necessary to model capacity limitations and determine how shipments are allocated across vehicles.

Vehicle volume constraints	Volume constraints specify the maximum cargo space available in each vehicle. Together with payload constraints, this ensures realistic modeling of loading decisions.
Vehicle transport cost per km	This attribute defines the variable cost of operating a vehicle per distance unit. It is essential for calculating total transport costs and evaluating different routing and consolidation strategies.
Vehicle fill rate	Fill rates indicate the degree of capacity utilization of vehicles, typically expressed as a percentage of payload or volume usage. This data is required to model consolidation efficiency and to reflect real-world transport planning practices.
Pick-up frequency	Pick-up frequency defines how often transport operations are scheduled from a given origin. This parameter is required to model regular transport patterns, such as daily or weekly collections, and influences both lead times and inventory dynamics.
Pick-up dates	Pick-up dates specify the exact timing of when shipments are collected. This data enables time-based simulation of flows and is necessary for modeling variability and synchronization between nodes.
Drop-off dates	Drop-off dates define when shipments arrive at their destination. Together with pick-up dates, this allows the simulation to capture transit times and evaluate service levels, such as delivery reliability and adherence to schedules.

7.2.5. Table of Total Data Requirements

Overall, the identified data requirements define the minimum set of inputs necessary to be able to accurately represent Scania's current inbound logistics network. By specifying attributes across suppliers, cross-docks, production units and transports, both the physical configuration of the network and the behavior of material flows can be consistently modeled. These data elements collectively enable the evaluation of how changes in the supply base and network design affect the chosen KPIs to monitor. To provide a structured overview, Table 20 summarizes all identified data requirements across the four component categories, serving as a consolidated reference for the inputs needed for Scania to achieve simulation readiness.

Table 20: Data requirements for the simulation model.

Suppliers	**Cross-dock**	**PRU**	**Transport**
Location/Coordinates	Location/Coordinates	Location/Coordinates	Pick-up location
Order weight	Sorting capacity	Demand	Drop-off location
Order volume	Sorting speed		Loading time & unloading time
Order destination	Processing costs		Vehicle fuel type
			Vehicle fuel consumption
			Vehicle payload constraints
			Vehicle volume constraints

			Vehicle transport cost per km
			Vehicle fill rates
			Quantity of available vehicles
			PUD frequency
			Pick-up dates / times
			Drop-off dates / times

7.3. Data Availability Mapping

This section maps the actual data available within Scania's systems against the previously identified data requirements. To conduct this mapping, a selection of representative inbound transport flows are examined, deliberately excluding specific flows in accordance with the conceptual model's established simplifications. The data gathering process is highly exploratory, utilizing a method inspired by a "snowball" sampling approach. This is done by searching through Scania's internal databases and platforms, complemented by unstructured questions to relevant functions and employees. The answers received from these initial contacts provides leads that allow for deeper research into specific functions, systems, and data insights.

By investigating several distinct flows in parallel, this part aims to cross-validate the accessibility of the required data. For this reason, the selected flows act as illustrative examples that represent the general data availability for the defined conceptual model. It should be noted that because every individual flow within the RMC Nordic network is not evaluated, this mapping may not provide a 100% comprehensive picture of data availability across all operations. However, given the time constraints of the thesis project and the intentional simplifications during the conceptual modeling phase, this delimited approach is aligned with the predefined methodology and provides a baseline to facilitate the future implementation of a simulation model.

7.3.1. Data Evaluation Matrix

As outlined in the methodology, a specific region with high data availability was selected to ensure a structured and representative mapping process. Within RMC Nordic's network, the Jönköping region was specifically chosen as this primary baseline due to its operational stability, guided by the empirical insights from the flow engineering team (Interviewees K_i & L_i). Although the Jönköping region serves as the primary baseline, the remaining RMC Nordic regions are also considered in the data mapping process to allow cross-validation.

To ensure the data availability mapping aligns with the established conceptual model, the evaluation within this region is structured around the three defined transport archetypes: (1) a pre-collection flow, (2) a direct flow, and (3) a consolidated TL flow. For each of these archetypes, the specific flows exhibiting the highest transport volumes are used as the baseline for the data mapping process. These flows are prioritized because they constitute the most critical and value-contributing segments of RMC Nordic's inbound logistics network. Using data retrieved from Scania's aggregated data lake via internal PowerBI reports, the results of this mapping - evaluated against the identified data requirements for the conceptual model - are presented in Table 21.

Though the data evaluation categories all concern data requirements, the definitions of each category varies slightly. The *Availability* category evaluates whether or not the data point is actually available at all in any of Scania's systems, regardless of which database the data points can be found in. Therefore, a partial or unavailable rating in this category means that data is not recorded at all, or that data is partially recorded, but not to a fully sufficient extent for supporting operational simulation capabilities. *Accessibility* refers to whether or not the data is available to fetch from internal data lakes or systems for example. Partial or unavailable ratings in this category mean that while data exists, it is hard or impossible for the simulation model analyst to get the data. Lastly, the *Quality* category concerns whether the data is truthful to the actual performance of the processes which it measures and if the format of said data is in a correct format for input into the conceptual simulation model.

Legend:

Available — data exists, accessible, sufficient quality for simulation Partial — data exists but requires significant manual effort, is fragmented, or quality is insufficient Unavailable — data does not exist or cannot be extracted; gap to be addressed N/A — not applicable to this specific flow **LC** Logistics Cost **LT** Lead Time **CO_2** Emissions **SL** Stock Level

Table 21: Data evaluation matrix for simulation readiness assessment.

Data Requirement			**KPIs Fed**	**Evaluation**			**Action / Gap Note**	
Component	**Attribute**	**Why required**		**Availability**	**Accessibility**	**Quality**	**System / source**	**Notes**
Suppliers	**Location / coordinates**	Positions the supplier node in the network; enables distance and routing calculations between suppliers, cross-docks and PRUs.	LC LT CO_2	**Available**	**Available**	**Available**	Information available internally and in PowerBI reports	No action required
	Order weight	Defines shipment mass; required for vehicle capacity utilization, consolidation decisions and transport cost and CO_2 calculations.	LC CO_2 SL	**Partial**	**Available**	**Available**	PowerBI report	Detailed data for pre-collection flow missing
	Order volume (m^3)	Captures physical space required per shipment; needed alongside weight for realistic loading constraint modeling in LTL and MR flows.	LC CO_2 SL	**Partial**	**Available**	**Available**	PowerBI report	Detailed data for pre-collection flow missing
	Order destination	Specifies receiving node (PRU or cross-dock); defines network links and flow paths to enable the construction of the flow structure.	LC LT CO_2 SL	**Available**	**Available**	**Available**	Information available internally and in PowerBI reports	No action required
Cross-dock	**Location / coordinates**	Positions the intermediate node; enables routing alternatives between suppliers, cross-docks, and PRUs and distance-based KPI calculations.	LC LT CO_2	**Available**	**Available**	**Available**	Information available internally	No action required
	Sorting capacity (units/hr or day)	Defines maximum throughput; required to model capacity constraints, queuing and bottleneck effects when volumes change.	LC LT SL	**Unavailable**	**Unavailable**	**Unavailable**		
	Sorting speed (processing rate)	Rate at which goods are processed at the cross-dock; directly contributes to dwell time and therefore total lead time.	LT SL	**Unavailable**	**Unavailable**	**Unavailable**		
	Processing costs (per unit/pallet)	Cost of handling at cross-dock; required to evaluate the economic impact of indirect versus direct flow routing.	LC	**Available**	**Available**	**Available**	Available in internal system (PackIT)	Defined differently for Jönköping (€/kg) and Nykvarn (€/pallet) cross-docks
PRU	**Location / coordinates**	Positions the destination node; determines transport distances from suppliers or cross-docks and is essential for cost, lead time and CO_2 calculations.	LC LT CO_2	**Available**	**Available**	**Available**	Information available internally	No action required
	Demand / consumption rate	Defines required inflow and the steady-state consumption rate (q); drives flow volumes and enables modeling of the PRU stock buffer ($Q_t = Q_{t-1} + e_t - q$).	LC LT SL	**N/A**	**N/A**	**N/A**	N/A	Not applicable due to steady state equilibrium assumption

Continued on next page

Table 21: Data evaluation matrix for simulation readiness assessment. (Continued)

Data Requirement			KPIs Fed	Evaluation			Action / Gap Note	
Component	**Attribute**	**Why required**		**Availability**	**Accessibility**	**Quality**	**System / source**	**Notes**
Transport flows	**Pick-up location**	Defines the origin node of each transport leg; establishes the starting point of movement in the network.	LC LT CO_2	Available	Available	Available	Information available internally	No action required
	Drop-off location	Specifies the destination node; together with pick-up location, defines the transport links that connect nodes across the network.	LC LT CO_2	Available	Available	Available	Information available internally	No action required
	Loading time & unloading time	Time required for handling at origin and destination; contributes to total lead time and processing cost calculations.	LC LT	Unavailable	Unavailable	Unavailable		
	Vehicle fuel type	Required to differentiate transport modes on cost structure and environmental impact; drives emission factor selection in CO_2e calculations (Eq. 7.3).	LC CO_2	Available	Available	Available	PowerBI reports	No actions required
	Vehicle fuel consumption (liters/km)	Defines fuel consumed per km for each truck type; used in dynamic CO_2e calculation and can affect variable transport cost.	LC CO_2	Available	Available	Available	Information available internally and in PowerBI reports	No action required
	Vehicle payload constraint (kg)	Maximum allowable weight per vehicle; necessary to model capacity limits and simulate fill rate.	LC CO_2 SL	Available	Available	Available	Information available internally and in PowerBI reports	No action required
	Vehicle volume constraint (m^3)	Maximum cargo space available; together with payload, ensures realistic loading and consolidation modeling for mixed flows.	LC CO_2 SL	Available	Available	Available	Information available internally and in PowerBI reports	No action required
	Vehicle transport cost per km	Variable operating cost per distance unit; essential for transport cost calculation and comparing routing and consolidation strategies.	LC	Partial	Available	Available	Information available internally	Regional rate tables contains payweight (PW) costs, but there is no corresponding cost/km available.
	Vehicle fill rate (% of capacity)	Degree of capacity utilization; required to model consolidation efficiency and reflects real-world planning targets.	LC CO_2	Partial	Available	Available	PowerBI reports	Detailed data for pre-collection flow missing
	Pick-up frequency (PUD / week)	How often collections are scheduled from a given origin; influences batching behavior, lead times and inventory dynamics at downstream nodes.	LC LT SL	N/A	N/A	N/A		
	Pick-up dates / times	Exact timing of collections; enables time-based simulation and modeling of variability and synchronization between nodes.	LT SL	Partial	Partial	Partial	PowerBI reports	Only dates available, no specific time for pick-up.
	Drop-off dates / times (transit time)	Arrival timing at destination; together with pick-up dates captures stochastic transit times and enables service level and delivery reliability evaluation.	LT SL	Partial	Partial	Partial	PowerBI reports	Only dates available, no specific time for drop-off.

As can be seen in Table 21, a large share of the data required is generally accessible and of sufficient quality. Core network structure data, such as supplier and node locations, transport links, vehicle characteristics, transport costs and high-level flow information, are largely available through internal systems and PowerBI reports. At the same time, there is a lack of sufficiently granular, process-oriented and time-based operational data required to accurately represent the network in a DES environment based on field data. In particular, detailed timestamps and operational parameters related to loading, unloading, cross-dock processing and exact pick-up and drop-off times are either fragmented, partially available or entirely missing. Furthermore, some data related to pre-collection flows, fill rates and cross-dock processing capacity could not be consistently identified across systems.

A notable exclusion from the data availability mapping is the data concerning sequence parts. As identified during the interviews and through the exploration of internal PowerBI reports, sequential order data is currently missing from the aggregated network volume data. Although this data gap was intentionally bypassed in the data availability matrix due to the conceptual model's defined assumptions and simplifications, the absence of sequence part data remains a considerable technical limitation that limits the completeness of the presented volumes and hinders the possibilities for an accurate, comprehensive simulation model in the future.

Given the current limitations in data granularity and operability, simplifications and assumptions are necessary to make future simulation implementation feasible. Nevertheless, the results suggest that Scania has a sufficiently strong technical and informational baseline to begin developing simulation-based decision support iteratively, provided that the identified data gaps and structuring issues are systematically addressed. Recommendations for addressing these gaps will be elaborated in the next chapter.

8 Simulation Framework

As illustrated in the final stage of the analytical structure (Figure 30), the insights from the Gap Analysis culminate in the development of the Simulation Framework. This chapter presents the Simulation Framework, serving as a roadmap designed for RMC Nordic to enable simulation-based decision support for their inbound logistics network.

To connect the findings from the Gap Analysis with recommended future steps, this chapter is structured around the three components outlined in Figure 30:

1. **Readiness assessment:** First, this chapter evaluates RMC Nordic's current state through a simulation readiness assessment that focuses on technical prerequisites, organizational structures and the strategic value of simulation.
2. **Shortlist of missing data:** Second, it summarizes the critical data gaps identified during the mapping process that must be bridged before proceeding.
3. **Implementation roadmap:** Building upon this initial readiness assessment and data evaluation, a structured five-phase approach is presented.

This framework is designed to guide RMC Nordic from its current state toward establishing a foundation for integrating simulation technology into its logistics network design.

8.1. Current Simulation Readiness Assessment

Based on the empirical findings, the As-Is Analysis and the identified gaps, RMC Nordic's current readiness for simulation-based decision support can be assessed across three dimensions: organizational readiness, technical readiness and the perceived value of simulation. It is important to first establish the current situation as there is a need for adequate data availability, organizational alignment and clear use-case justification to ensure successful simulation projects (Kuhnt and Wenzel, 2010; Laguna and Marklund, 2019).

8.1.1. Technical Readiness

From a technical perspective, RMC demonstrates several enabling conditions, along with some limitations related to data structuring and modeling capability. Unsurprisingly - and the reason for this thesis - one obvious limitation is the absence of a dedicated simulation environment. As identified in the current tool assessment, existing tools primarily consist of Excel-based models which support deterministic calculations rather than dynamic system representation. This constrains the ability to capture interdependencies and time-based system behavior, as highlighted in both the empirical findings and the Gap Analysis.

Data availability constitutes a central challenge, both in terms of granularity and structure and in the absence of specific data points. The data availability matrix (Table 21) shows that while high-level performance measures often are available, the underlying process data required to model how these outcomes are generated is often incomplete or fragmented, with examples including lacking available data on processing times for cross-docks and insufficiently granulated pick-up and drop-off data for transports. Simulation requires data on the component processes and activities that drive system behavior, such as transport times per leg, handling and processing times at nodes, and flow-specific operational characteristics. Where such data is missing, dispersed or insufficiently recorded, it becomes difficult to perform input analysis and construct empirically grounded representations of system dynamics. While historical observations of outputs such as total lead times from pick-ups at suppliers and drop-offs at PRUs can support validation, they are not sufficient to explain or simulate how changes in the system affect performance. Data such as pre-collection- and sequence part orders also aren't readily available, leading to large gaps which hinder the possibilities for an accurate, comprehensive simulation model. Due to the assumptions and simplifications stated in Table 14 & 15, this problem isn't reflected in the data availability matrix (Table 21), yet remains a considerable technical limitation. Furthermore, as identified in the empirical findings, the lack of disaggregated performance follow-up also limits the ability to consistently validate model outputs against real system behavior. Suppliers and transport carriers are also not fully integrated into Scania's systems, limiting access to key operational data required to model flows accurately. External interviews suggest that this is a common constraint and may require formalized data-sharing mechanisms.

At the same time, there are clear technical enablers. Scania is currently undergoing an ERP transformation aimed at consolidating legacy systems into a unified SAP environment. As indicated in interviews and internal documentation, this is expected to improve data accessibility, consistency and integration across functions. This consolidation creates favorable conditions for simulation, particularly by enabling centralized data structures and continuous model updating. In addition, employees within inbound logistics regularly work with digital systems for tracking and calculating costs, emissions, and lead times, indicating a high level of digital maturity. Internal platforms and intranets further support information sharing and learning across the organization.

Overall, Scania's technical readiness is developing. However there are significant limitations related to data availability, validation and integration. Ongoing system consolidation and strong digital capabilities provide a solid foundation for future implementation, but in its current state, the technical readiness is not suitable for pursuing a simulation model without taking necessary steps to mitigate data availability problems.

8.1.2. Organizational Readiness

Organizationally, RMC Nordic combines strong analytical capabilities with structural challenges related to coordination and ownership. A limiting factor is the low level of experience with simulation. Internal interviews indicate that several respondents are unfamiliar with how simulation could be applied in their context. This reflects a gap in simulation-specific competence, consistent with literature emphasizing the need for organizational understanding to realize value from such tools (Liotta, 2012). In addition, the organizational structure is highly disaggregated, with responsibilities distributed across multiple functions. While this supports local optimization, it results in sequential decision-making, informational handovers and limited cross-functional accountability. As identified in the As-Is Analysis, this reduces incentives to consider downstream effects, which complicates the development of system-wide simulation models. The lack of a clearly defined owner for simulation initiatives further reinforces this challenge.

However, several organizational strengths counterbalance these limitations. Scania's logistics organization places strong emphasis on analysis and continuous improvement, with functions regularly evaluating and redesigning logistics setups. Moreover, the organization possesses a high level of domain expertise. Interviews highlight the presence of skilled personnel with deep operational knowledge, which is critical for conceptual modeling, input analysis, and model validation. This reduces the barrier to adopting new tools and concepts. RMC Nordic also demonstrates a strong culture of information sharing and learning. Cross-functional forums, internal platforms, and regular site visits across the network enable employees to develop a system-wide understanding of logistics flows. While formal structures may be disaggregated, these practices mitigate the impact of silos and support the type of systemic perspective required for simulation.

Finally, as a large organization within the TRATON Group, Scania has access to substantial resources. This reduces financial barriers to implementation and enables investment in both technical infrastructure and competence development. Potential future consolidation of logistics networks within TRATON, as discussed in interviews, may further increase system complexity and dependencies and thereby strengthen the rationale for simulation. In summary, RMC Nordic's organizational readiness is mixed. Structural fragmentation and limited simulation experience pose challenges, but strong analytical capabilities, skilled personnel, and a collaborative culture provide a solid foundation for adoption.

8.1.3. Value of Simulation

Lastly, the potential value of a simulation tool for RMC Nordic should be established, to take the commercial value in consideration. For example, a current limitation is the lack of clearly articulated use cases at the functional level. As identified in interviews and the empirical findings, individual functions have difficulty linking simulation to their specific decision-making processes. This is partly due to limited performance follow-up across functions, which makes it difficult to quantify downstream impacts and, in turn, the benefits of improved system-level analysis. Despite this, several factors indicate substantial potential value. First, the inbound logistics network itself is highly complex, involving numerous suppliers, transport flows and intermediate nodes. Literature suggests that such environments favor simulation over analytical models, as they involve non-linear interactions and dynamic behavior (Stefanovic et al., 2009).

Second, decisions made early in the value chain, particularly in procurement and flow engineering, have significant downstream effects on transport performance, lead times and costs. As highlighted in the empirical findings, these effects are currently difficult to quantify. Simulation offers a way to explicitly model these interdependencies and provide decision-makers with a more complete understanding of system-wide consequences. Furthermore, the scale of Scania's operations increases the value of predictive analysis. Implementing changes in the logistics network requires coordination across multiple functions and stakeholders, making experimentation in the real system costly and time-consuming. Here, simulation can serve as a relatively low-cost testing environment, complementing existing analytical tools by enabling scenario evaluation before implementation. Finally, potential integration within the TRATON Group further strengthens the value proposition. A more interconnected logistics network would increase both complexity and interdependencies, making traditional analytical approaches less sufficient and increasing the relative benefit of simulation-based decision support.

At the same time, challenges remain. Demand variability driven by Scania's modular product structure introduces uncertainty into model inputs, which may affect trust in simulation outputs. Additionally, increasing model scope improves insight but also raises complexity and maintenance requirements, reflecting a trade-off highlighted in the literature (Robinson, 2013). Overall, while the current perceived value of simulation is limited by unclear ownership and use cases, the structural characteristics of Scania's logistics network indicate strong potential for simulation to support decision-making, particularly in evaluating complex, system-wide changes.

8.2. Shortlist of Missing Data

As established in the data availability mapping section in the previous chapter, transitioning to an operational simulation model requires identifying and bridging specific informational gaps. Table 22 provides a summary of the exact data points that are perceived as crucial and that RMC Nordic currently are missing or lack sufficient quality to populate the conceptual model.

Table 22: Summary of insufficient data required for the conceptual model.

Data Requirement		Evaluation			Action / Gap Note
Component	**Attribute**	**Availability**	**Accessibility**	**Quality**	**Notes**
Suppliers	**Order weight**	**Partial**	**Available**	**Available**	Detailed data for pre-collection flow missing.
	Order volume (m^3)	**Partial**	**Available**	**Available**	Detailed data for pre-collection flow missing.
Cross-dock	**Sorting capacity**	**Unavailable**	**Unavailable**	**Unavailable**	Not found in internal data systems. Required to model cross-dock throughput constraints and potential bottlenecks.
	Sorting speed	**Unavailable**	**Unavailable**	**Unavailable**	Not found in internal data systems. Required to estimate processing time and cross-dock dwell time.
Transport flows	**Loading and unloading time**	**Unavailable**	**Unavailable**	**Unavailable**	Not found in internal data systems. Required to capture handling time at transport origin and destination.
	Pick-up and drop-off times	**Partial**	**Partial**	**Partial**	Only dates are available; exact times are missing. Required for simulating precise lead times.

8.3. Five-Phase Implementation Roadmap

To successfully transition from the conceptual model established earlier, to a fully operational decision-support tool, a structured approach is required. To manage this transition, external simulation experts (Interviewees T_e and Q_e) advocate for a ”hierarchical modeling methodology”, where the organization starts at a high level and iteratively go into lower level of detail only when necessary. Guided by these principles, the following five-phase implementation roadmap has been develop to help Scania sequentially build the required organizational and technical capabilities.

8.3.1. Phase 1: Establishing Organizational and Technical Prerequisites

During the first phase, foundational resources and tools must be defined to enable a structured and sustainable simulation capability. This includes establishing clear ownership, allocating appropriate competencies and selecting suitable software to support model development.

A clear ownership structure is necessary to ensure continuity in model development, validation, and long-term maintenance. As identified in the empirical findings and As-Is Analysis, there is currently no clear owner of a potential simulation capability and only a limited number of roles have insight into the full end-to-end logistics flows. Without a defined owner, simulation initiatives are likely to remain exploratory rather than integrated into decision-making processes. It is therefore recommended to assign ownership to a product owner within OLNC, responsible for coordinating development and aligning the simulation capability with existing digital infrastructure. This role should be supported by a small cross-functional team, combining analytical competence with operational knowledge from logistics and procurement.

In parallel, an appropriate simulation tool must be selected. The software should support DES, as this aligns with the process-oriented and event-driven nature of inbound logistics flows. It should also enable integration with Scania's internal data systems and future ERP environment to facilitate access to structured input data and allow for efficient model updates, which is particularly relevant given the ongoing system consolidation described in the empirical findings. A third-party simulation software is recommended over in-house development. According to Laguna and Marklund (2019) ten-step simulation procedure, the use of established tools is preferred due to their tested functionality, built-in statistical capabilities, and support for standardized modeling practices. This reduces development effort and methodological risk, allowing the organization to focus on model design and input analysis rather than software engineering. This perspective is also reflected in the external interviews, where in-house solutions were associated with higher maintenance requirements and slower implementation (Interviewees T_e, R_e & O_e). Finally, visualization and animation capabilities should be considered, as they facilitate communication of model behavior and support cross-functional understanding, which was identified as a key enabler by the external experts.

8.3.2. Phase 2: Data Acquisition and Structuring

To systematically acquire the missing information presented in Table 22, a three-level strategy is recommended. First, Scania should search freely across its internal systems to locate the missing data. Second, once located, this data should be integrated into Scania's aggregated data lake and connect to the current PowerBI reporting structure. Third, to ensure long-term simulation readiness and data accessibility, Scania is recommended to create a dedicated, centralized PowerBI report that exclusively gathers and presents all the identified data requirements for the simulation model in one place.

In cases where specific data points cannot be found or accurately abstracted, this must not hinder Scania from pursuing simulation modeling. As emphasized by external simulation experts, perfect data rarely exists in industrial practice (Interviewee Q_e, R_e, T_e & V_e). If historical data is unavailable, the primary recommendation is to create a basic representation of the missing variables through qualified estimates, and apply statistical approximations, such as triangular distributions based on minimum, maximum and most likely values, to bridge these gaps. Ultimately, data limitations should not prevent the organization from adopting simulation-based decision support.

Flow Unit Conversion

To successfully implement a simulation model of DES character, physical material flows must be represented as discrete, trackable entities - previously referred to as "flow units". Attempting to simulate every individual part size and packaging variant would introduce excessive computational and structural complexity. Standardizing these diverse materials into a single, homogeneous flow unit, such as a standardized pallet, drastically simplifies the model without compromising its strategic value.

To ensure valid and reliable simulation results, Scania must take strict ownership of defining this flow unit and establishing the underlying conversion logic for traditional measurements like total weight (kg) or volume (m^3), since this raw data cannot be fed directly into a DES model. Scania must formally define the mathematical and logical rules to translate these continuous measurements into discrete units. Practically, this entails establishing a standardized capacity threshold for the chosen flow unit (e.g., the maximum weight, volume capacity or a combined measure for a standard pallet). This has to be done by applying a conversion factor to the raw transport order data to generate a discrete number of units. It is crucial that Scania establishes and maintains this conversion, as the accuracy of the simulation's capacity constraints and fill-rate evaluations relies on the consistency of these standardized inputs.

8.3.3. Phase 3: Input Analysis and Model Building

In this phase, collected data is translated into model inputs and the conceptual model is implemented in a simulation environment. This corresponds to the input analysis and model building steps described in the literature. Historical data should be used to estimate input distributions where relevant. Most commercial simulation softwares include built-in tools for distribution fitting, allowing observed data, such as transport times or handling times, to be fitted to theoretical probability distributions directly within the tool. Importantly, statistical fitting is only required for process-related components that drive system behavior such as transports, sorting in cross-docks and material handling processes. Other data types - such as network structure, routes, storage data or other deterministic parameters - do not require input analysis and can be implemented directly.

Model development should follow an iterative approach. It is recommended to start with a simplified representation of the network and gradually increase scope and detail as the model is developed. This approach is supported both by simulation literature and external expert interviews and reduces the risk of excessive complexity in early stages which can lead to trouble identifying bugs and modeling mistakes.

Furthermore, the model should be constructed at a level that is at least one layer deeper than the defined output KPIs. Rather than directly modeling outcomes such as total lead time or cost, the model should represent the underlying processes that generate these outcomes. This enables analysis of cause–effect relationships and provides explanatory power when evaluating how and why KPIs change under different scenarios.

8.3.4. Phase 4: Validation and Output Analysis

To ensure that the modeled processes mimic reality as accurately as possible, Scania must differentiate between "model verification" (ensuring the software logic is coded correctly and free of bugs) and "model validation" (confirming that the model's behavior authentically reflects the actual physical system) (Interviewee T_e). The primary approach to validation should be data-driven, which involves running the simulation based on historical data and comparing the outputs against real-world metrics. More specifically, this means running a simulation under the exact same condition as the real world and checking if the model's outputs match reality (Laguna and Marklund, 2019). For example, if historical data shows that a truck takes 72 hours to travel a specific route, the model is considered valid if it reliably produces a similar 72-hour time frame (Interviewee T_e).

In the case of the proposed conceptual model, Scania can for example validate the model by observing the total throughput time of a standardized flow unit in a simulation run and comparing it to the estimated corresponding actual time. A deeper validation analysis can reveal whether the waiting times incurred by the model, such as queuing delays, are realistic. If differences exists, the modeled capacities, resources or processing times must be iteratively refined to reflect reality more accurately. However, in scenarios where historical data is unavailable, such as when testing entirely new strategic logistics concepts, Scania should rely on ”face validation” (Interviewee T_e, Laguna and Marklund (2019)). This involves presenting simulated behaviors or visual animations to external experts to confirm whether the system's dynamics visually and logically match expected reality.

Even though model validation is inherently important, there exists a trade-off between validity and effort. Interviewee R_e highlights that there is a steep trade-off curve between the effort put into validation and the resulting value. While initial validation efforts quickly yield significant improvements in the model's reliability, trying to achieve a 100% valid model requires an infinite amount of effort and is ”practically impossible”. Therefore, Scania model developers must identify a practical breaking point where the model is ”good enough” for its intended purpose.

Output Analysis

To benefit strategically from simulation-based decision support, and especially gain clarity in how supply base changes affect RMC Nordic's inbound logistics network, Scania must perform a rigorous output analysis of the results generated by the simulation model. Because DES mimics the inherent uncertainty of a real-world scenarios, its outputs are not static, deterministic answers. As explained in Section 4.3.3.3, outputs are stochastic variables that form probability distributions. Therefore, for Scania to evaluate ”what-if” scenarios, such as on-boarding new suppliers or shifting geographic sourcing regions, the output analysis will have to include statistical comparisons of the performance distributions of the new configuration against the ”as-is” baseline. By evaluating the means, variances and confidence intervals of the four defined KPIs, Scania can accurately conduct a comparative scenario analysis.

Performing this output analysis highlights the profound advantage of using simulation over traditional analytical models. Analytical models typically rely on fixed averages and restrictive assumptions, making them inadequate to capture complex system variations and statistical interdependencies (Laguna and Marklund, 2019). For example, a static analytical calculation cannot accurately predict how a shift in upstream volume or lead time from a new supplier will fragment consolidation of goods at cross-docks or other consolidation centers, since the non-linear delays cannot be captured in an analytical equation. In contrast, the output data from a simulation model naturally captures these dynamic structural trade-offs, transient behaviors and capacity constraints under uncertainty. By analyzing the statistical outputs, RMC Nordic's decision-makers can go beyond static mathematical estimates and quantitatively prove whether a hypothetically cheaper sourcing setup might increase the variability of total lead times or if it will require larger buffer stocks locally at PRUs to maintain the same delivery reliability as the baseline setup.

8.3.5. Phase 5: Model Maintenance and Continuous Development

Following model validation and initial deployment, in the longer term, the simulation capability must be continuously maintained to remain relevant for decision-making. As highlighted in the empirical findings, Scania's logistics network is subject to frequent changes driven by supplier shifts, transport reconfigurations and external uncertainties, requiring continuous adjustments to operations. This need for continuous updating is further reinforced by external simulation experts, who emphasize that simulation models must evolve alongside the system they represent. Without ongoing updates, models risk becoming outdated shortly after development, effectively reducing their practical value. Given that simulation models are intended to support decision-making in a changing environment, misalignment between the model and the real system can lead to misleading outputs and reduced trust in the tool.

To mitigate this, the model must be kept architecturally aligned with the real-world network. This includes continuously updating the supply base, reflecting changes in network structure and ensuring that all transport flows correspond to current tendered contracts. Transport-related parameters such as pricing structures, routing logic and vehicle configurations must be regularly updated, as these directly influence key performance outputs. In parallel, the process data driving modeled activities must be kept up to date. Since system behavior is determined by process-level inputs, these should be continuously fed into the model either through automated data integration or through structured manual updates at regular intervals. The appropriate approach depends on system maturity, but regular updates are necessary to prevent model drift.

Beyond maintenance, the model should be continuously expanded in scope and level of detail. Initial implementations may focus on a limited part of the network (such as in this thesis where RMC Nordic is in scope), but additional components, flows and processes should be incorporated over time. Expanding the model reduces the need for simplifying assumptions and black-box representations, thereby increasing the explanatory power and the degree to which model outputs reflect the underlying system behavior. This aligns with the iterative modeling approach emphasized in both the literature and external expert interviews, where models are gradually refined as more data and understanding become available. Overall, the simulation model should be treated as a living decision-support system, requiring continuous updates and incremental development. This ensures that the model remains aligned with the evolving logistics network and increases its reliability as a basis for decision-making over time.

9 Conclusion and Discussion

The purpose of this chapter is to conclude the thesis by summarizing and discussing the main findings in relation to the research objectives and the overall purpose of the study. The thesis aimed to examine how simulation-based modeling can be enabled as a decision-support approach for evaluating supply base changes and their impact on logistics flows and system performance in real industrial contexts. Rather than focusing on simulation model development itself, the study investigated the organizational, informational and technical prerequisites required to establish such capabilities in practice. Through a case study at Scania, the research sought to ground these challenges in an industrial setting and generate insights into how simulation-based decision support can be operationalized within a complex logistics organization. In doing so, the study aimed to contribute both practically and theoretically by strengthening understanding of how simulation can support more proactive decision-making in supply chain design. Accordingly, this chapter presents the theoretical and practical contributions of the study, reflects on research quality and limitations, and discusses implications for future research and the continued development of simulation-based decision support within logistics network design.

9.1. Conclusions From Research Objectives

RO1: *Explore existing theoretical perspectives and best practices in industry for simulating the logistics network design.*

The first research objective was addressed through a structured literature review and complementary interviews with external experts in supply chain simulation. The literature review examined theoretical perspectives in logistics and supply chain management as well as simulation-based decision support, focusing on how these areas interact. In parallel, interviews with external experts provided industry-based best practices into how simulation is implemented and what prerequisites there are.

The findings showed that simulation is positioned in the literature as a suitable tool for decision-making in complex and uncertain supply chain environments, particularly due to its ability to capture dynamic interactions and non-linear effects that traditional analytical models struggle to represent. Key enablers include structured input and output analysis, clearly defined modeling assumptions and the availability of granular and reliable data. The literature further highlights that simulation requires alignment between organizational structures, information flows and decision-making processes.

The empirical findings reinforced this by emphasizing that successful simulation implementation depends not only on technical capabilities but also on organizational readiness. This includes cross-functional collaboration, standardized data structures and clearly defined use cases. A recurring limitation identified in literature is the effort required for data preparation and integration, which often constrains implementation.

RO2: *Investigate how decisions regarding logistics network design are currently made at Scania.*

The second research objective was addressed through 19 interviews with internal Scania stakeholders, complemented by the analysis of internal documents, archival records, and observations. These activities enabled a detailed mapping of current decision-making processes related to logistics network design, including roles, processes, information flows and decision-support tools.

Network design decisions at Scania are distributed between Procurement and RMC Nordic. Procurement determines the supplier base through supplier selection, whereas RMC Nordic designs the transport structure by defining how material flows from suppliers move throughout the logistics network to ultimately arrive at PRUs. As a result, logistics network design is not centralized within a single function but instead falls under both functions' responsibility, where Procurement's decisions can be viewed as an input to the network design decisions RMC Nordic has to make.

The findings indicate that supplier selection is driven by Procurement through the TQDCS framework. During this process, Procurement initially identifies and nominates a set of potential suppliers and subsequently requests logistics-related input from RMC Nordic, in the form of cost estimations and supplier ratings. These inputs are incorporated into the supplier evaluation process and are intended to support sourcing decisions. However, despite being an intended part of the evaluation, these logistics inputs have been neglected by Procurement multiple times, leading to sourcing decisions made without sufficient consideration of their true logistical implications. Several interviewees emphasized cost as a central driver behind supplier selection decisions. This creates a situation where lower purchasing costs can be prioritized even when they generate downstream implications for logistics operations. Respondents within RMC Nordic described how supplier choices can create increased operational complexity, resulting in additional disruption handling, emergency shipments, supplier support activities and efforts aimed at improving suppliers' internal logistics capabilities. Such consequences generate hidden costs throughout the supply chain which are not necessarily visible during the supplier selection process or attributed to it. Since these costs arise downstream and outside Procurement's area of responsibility, there appears to be limited incentives to evaluate decisions from a system-wide perspective.

To support network design decisions, RMC Nordic mainly relies on Excel-based tools to conduct cost- and case-based calculations. However, multiple interviewees questioned whether these calculations accurately reflect actual system behavior. Respondents highlighted that current analyses rely on simplified assumptions and static calculations which do not sufficiently capture interdependencies across the logistics network. As a result, system-wide effects and indirect consequences may be difficult to identify beforehand. The hidden costs described by interviewees further support this observation and indicate that current decision-support approaches fails to sufficiently capture the supply chain complexity. At the same time, RMC Nordic currently lacks formal processes for systematic performance follow-up and validation after network changes have been implemented. Consequently, it remains difficult to objectively assess the accuracy of existing cost calculations and decision-support methods.

Taken together, the findings suggest several shortcomings in the current network design decision-making process. Existing tools are largely static, labor-intensive, and provide limited transparency regarding how costs emerge and are allocated throughout the logistics system. This creates a need for decision-support approaches capable of handling greater network complexity, reducing manual effort and enabling more disaggregated visibility of cost drivers and system-wide impacts. Simulation-based approaches possess characteristics that can address these shortcomings and therefore represent a potentially valuable complement to Scania's current decision-making process.

RO3: *Identify challenges and limitations related to simulation readiness, and develop a framework defining the steps needed to achieve the organizational and technical requirements to enable simulation readiness for Scania's logistics network design.*

The third research objective is addressed by synthesizing insights from the As-Is Analysis, internal interviews and archival records as well as the Gap Analysis, to develop a simulation readiness framework. The As-Is and Gap Analysis identifies several challenges that limit RMC Nordic's simulation readiness. The analysis of RMC Nordic's current operations reveals that, while a foundational baseline for simulation exists, the organization's overall simulation readiness is currently constrained by organizational, informational, and technical limitations. The proposed framework defines the necessary steps to satisfy the requirements for enabling simulation-based decision support within RMC Nordic.

Firstly, RMC Nordic currently lacks a clearly defined simulation use case. Although there is a recognized need to understand how strategic procurement decisions impact downstream logistics, the simulation model's intended use remains undefined. What it is supposed to simulate, who will be responsible for making decisions based on the results and which function that will be responsible for the maintenance and upkeep of the model inputs, are all unanswered questions which reduce simulation readiness. As established in the literature review and identified during the external expert interviews, attempting to initiate a simulation project without clearly defined objectives often leads to overly complex and unsuccessful models.

From a technical perspective, RMC Nordic possesses significant simulation readiness, but there are also notable gaps. To identify the informational limitations regarding RMC Nordic's simulation readiness, a simplified conceptual model based on DES was defined which guided a data evaluation process. The analysis showed that the data required for the heavily simplified simulation model of batch order flows, is available to a sufficient extent, meaning the organization is not hindered from initiating basic simulation efforts. However, data points considered critical for the conceptual model's functionality as a useful decision-support tool in actual operations have been identified as incomplete. Examples of the critical data points are key input parameters, such as processing times for transport activities and cross-dock operations. Since these are among the main activities that drive the business process in the conceptual model, it is imperative that they are accurately modeled. Basing these activities on assumptions will lead to a model in which the simulation is not sufficiently grounded in the system's actual behavior, making the outputs untrustworthy. Considering that DES relies on events, the lack of historical, granular event data significantly limits the simulation model's ability to capture time-based interdependencies in the supply chain. If the simulation model cannot capture such interdependencies, the value of simulation compared to traditional analytical tools drastically deteriorates. Moreover, sequence order data must also be accounted for to fully capture the entirety of RMC Nordic's inbound network. This data has however been identified as readily unavailable within RMC Nordic's internal systems, which further limits the simulation readiness.

Furthermore, for simulation to be an effective decision-support tool, current practices must be possible to validate to ensure that the simulation model accurately mimics reality. As identified in the As-Is Analysis, performance follow-up and validation is lacking. A key part of building a useful simulation model is validation of outputs to ensure that the model captures the network dynamics. Therefore, without access to granular data on subprocess performance in RMC Nordic's inbound supply chain, the model builder will not be able to validate the accuracy of the tool, leaving decision-makers unable to trust the simulation outputs and ultimately renders the model useless.

Finally, regarding organizational capabilities, there is currently no clear ownership or governance over simulation initiatives. However, the existing organizational structure indicates that work-groups such as OLNC, whose primary responsibility within RMC Nordic is to drive IT and digitization projects, can be viewed as a suitable department for ownership and governance of such initiatives. Regarding technical capabilities, the lack of previous experience with simulation techniques further reduces simulation readiness. Based on the findings, simulation is currently foreign to the organization as a whole, with no active initiatives or tools in use, highlighting a fundamental gap in technical simulation knowledge. Nevertheless, these limitations are counterbalanced by strong organizational assets - such as high analytical capabilities, deep operational expertise, a collaborative culture and substantial corporate resources - which collectively provide a solid foundation for future simulation adoption.

In conclusion, while RMC Nordic possesses prerequisites regarding necessary process knowledge, organizational structure, and baseline data to explore simulation, its current simulation readiness is limited by undefined objectives, gaps in critical time-event data, missing validation practices and a lack of technical simulation expertise and knowledge. Therefore, the conclusion of RMC Nordic's simulation readiness assessment is that they are currently not prepared to proceed with implementing a simulation model without a deliberate plan. This warranted the need for the Simulation Framework which outlined the necessary steps needed to achieve sufficient readiness.

The developed framework addresses these limitations through a phased approach, including establishing organizational and technical prerequisites, structuring and acquiring data, conducting input analysis and model building and implementing validation and continuous development processes. For Phase 1, the recommended course of action is to assign ownership of a simulation model to a new team member in OLNC which will drive the model building with help from a small cross-functional team that can help with data gathering and sub-tasks. Furthermore, the choice of whether or not to build a simulation model internally versus choosing a third party software needs to be established. In accordance with the literature review and insights from the external expert interviews, the choice of an external simulation software is however recommended due to the simplicity and extensive functionality available on the market.

Next for Phase 2, a systematic strategy for data acquisition is recommended to fill the informational gaps identified in the Gap Analysis. The creation of a centralized, dedicated PowerBI report is recommended to consolidate all relevant data points for the creation of the simulation model and make updating of the model quick and easy. For certain processes and operational data of which there is a lack of sufficient amounts or quality of data, assumptions and estimations need to be made. This should be done through manual sampling or qualified estimates by personnel with insight into the processes. Furthermore, a unified conversion to a standardized flow unit is recommended, to make interpretation of the results digestible and to reduce model complexity.

Phase 3 gives recommendations regarding input data and actual model building. Here, the recommendation is to utilize built-in distribution fitting tools which most simulation software have ready in order to have accurately modeled subprocesses and activities in the model. Furthermore, an iterative model building approach is recommended, similar to how the conceptual model was developed, where additional model complexity can be included once a previously simplified version is operable. The final model complexity should be capped at one layer deeper than the output KPIs which are relevant, to enable the analysis of cause-effect relationships in the system.

The recommendations in Phase 4 of the Simulation Framework refer to validation of the model accuracy and analysis of outputs. Here, using historical data to gauge whether the model can accurately predict system performance is recommended. This is done by inputting historical conditions and inputs into the model and then checking if the model outputs match the historical performance measurements. As for output analysis, statistical analysis needs to be made to compare different scenarios. This capability is readily available in most simulation softwares and therefore it is recommended to utilize these capabilities.

Lastly, Phase 5 recommends continuous maintenance and development of the model even after it is being used operationally. This is because Scania's logistics network is constantly changing, exposing the model to risks of becoming obsolete unless updated regularly. The scope of the model should also be expanded in regular intervals as the model's value increases when more parts of the system are included.

9.2. Contributions

This section discusses the contributions of the thesis from both a theoretical and practical perspective. It explains how the findings contribute to existing research on simulation-based decision support and logistics network design, while also outlining the practical value of the proposed framework for Scania and similar industrial organizations.

9.2.1. Theory

This master thesis contributes to existing theory by providing empirical insights that bridge the gap between theoretical concepts of simulation-based decision support and their practical application in complex industrial supply chains. While prior research highlights the potential of simulation as a tool for evaluating supply chain configurations (Persson and Olhager, 2002; van der Zee and van der Vorst, 2005; Tako and Robinson, 2012; Liotta, 2012; Wang and Moon, 2013), there remains limited empirical work demonstrating how simulation-based approaches can be operationalized in real industrial environments (Lu and Shang, 2017). Similarly, several authors note that simulation tools and frameworks are rarely translated into successfully implemented industrial applications (Alvanchi et al., 2011; Chahal et al., 2013). Furthermore, Guo et al. (2024)'s research points to a lack of applied studies demonstrating how simulation can function as an integrated decision-support mechanism linking strategic sourcing decisions with operational logistics performance. By grounding the analysis in a case study at Scania, this thesis addresses these gaps by demonstrating how changes in supplier structures and sourcing decisions can be connected to downstream logistics consequences and by translating theoretical simulation concepts into an implementation framework for a logistics network in a real, industrial manufacturing context. The positioning of this thesis' framework and recommendations - outlining prerequisites and steps to successfully lay the foundation for implementation of simplified, real network representations - targets the gap that the theory points to by utilizing a defensive and pragmatic approach that focuses on feasibility over model complexity.

Furthermore, this study contributes by extending understanding of simulation readiness in supply chain settings. While the potential of simulation-based decision support is well established, the organizational and technical prerequisites required for its effective use remain insufficiently understood in industrial contexts (Tako and Robinson, 2012; Kuhnt and Wenzel, 2010; van der Zee and van der Vorst, 2005). Existing research emphasizes the importance of data availability and cross-functional information exchange (van der Zee and van der Vorst, 2005), yet provides limited guidance regarding how organizations should prepare for implementation in practice. Rather than focusing on simulation model development itself, this thesis shifts attention toward the readiness phase and conceptualizes readiness as an organizational capability involving ownership structures, cross-functional alignment and data acquisition strategies. In doing so, the study extends existing theory by providing a more structured understanding of the prerequisites required to enable simulation-based decision support.

Finally, this thesis contributes by contextualizing organizational barriers to simulation implementation. Previous research suggests that integrated decision-making remains difficult because information is frequently fragmented across organizational functions, limiting visibility and preventing complete decision support (Dias and Ierapetritou, 2017; van der Zee and van der Vorst, 2005; Saisridhar et al., 2024; Liotta, 2012; Wong et al., 2012; Chopra and Meindl, 2013; Nakano, 2020). Likewise, traditional analytical approaches often rely on static assumptions that struggle to capture the complexity and dynamic behavior of modern supply chain organizations (Stefanovic et al., 2009; Saisridhar et al., 2024; van der Zee and van der Vorst, 2005). Through an analysis of Scania's current state, this study identifies practical constraints including fragmented information structures, undefined simulation objectives, limited technical expertise and insufficient data availability, effectively supporting the existing research's findings. By linking these barriers to theoretical requirements and mapping dependencies across organizational functions, the study contributes empirical findings of how organizational and informational constraints influence and hinder simulation adoption in industrial supply chain design despite their theoretical advantage over analytical approaches.

9.2.2. Practice

This master thesis contributes to practice by providing Scania with a structured and comprehensive understanding of its current logistics organization in relation to simulation-based decision support. The study consolidates insights from multiple functions, including logistics and procurement, and combines these with internal documentation and observed processes. This results in a holistic perspective on logistics network design and decision-making that is unlikely to be established within any single function in the organization. By synthesizing these perspectives, the thesis highlights current challenges, misalignment's and limitations that affect Scania's ability to evaluate and manage its logistics network effectively.

Furthermore, the thesis provides a clear assessment of Scania's current level of simulation readiness. By mapping data availability, technical infrastructure and organizational conditions, the study identifies the key barriers that currently limit the adoption of simulation-based decision support. Building on this, the developed framework outlines concrete steps required to overcome these barriers.

The contributions span multiple levels of complexity and time horizon. In the short term, the study provides actionable insights related to improving data accessibility, standardizing data structures and increasing cross-functional coordination. In the longer term, it outlines more comprehensive initiatives, such as establishing dedicated ownership of simulation activities and developing an integrated technical environment to support simulation modeling. In sum, the thesis contributes to Scania by laying the foundational groundwork for a potential simulation initiative. It provides a structured basis for evaluating the feasibility and value of simulation-based decision support and supports decision-makers in assessing whether and how to initiate such an effort.

Beyond Scania specifically, the thesis also contributes to industrial practice more broadly by illustrating how global manufacturing firms can approach simulation readiness as an organizational and technical challenge rather than solely a technical software implementation issue. Many manufacturing companies operate in similarly fragmented supply chain environments characterized by dispersed data ownership, legacy systems, and cross-functional decision-making structures (Prajogo and Olhager, 2012; Wong et al., 2012; Mentzer et al., 2001). The framework and findings presented in this thesis therefore provide a practical reference point for other organizations seeking to evaluate their own readiness for simulation-based decision support in logistics network design. In particular, the study contributes practical insights regarding the types of data structures, organizational conditions and process transparency required before simulation can generate operational value in complex industrial supply chains

9.3. Discussion

The discussion reflects on the broader implications of the study and the limitations and overall research quality of the thesis. It highlights areas where additional research is needed and proposes directions for future studies related to simulation readiness and simulation-based decision support in supply chain and logistics contexts.

9.3.1. Limitations and Research Quality

While this thesis provides a structured assessment of simulation readiness within Scania's logistics network, several limitations must be acknowledged. First, the study is delimited to the RMC Nordic organization. Although this enables a focused and in-depth analysis, the inbound logistics network is inherently interconnected with other regions and functions within Scania's global logistics system. As a result, certain interdependencies and system-wide effects are not fully captured, which may limit the completeness of the analysis.

A second limitation relates to the level of implementation. The thesis does not develop or test an actual simulation model, but instead focuses on defining the prerequisites required to enable such a model. This implies that the proposed framework and recommendations are not empirically validated through simulation experiments. While this is consistent with the scope of the study, it limits the ability to demonstrate how the recommendations perform in practice. Furthermore, the conceptual nature of the model and the required simplifications and assumptions raise unanswered questions regarding how accurately a future implementation would represent the complexity of the real system.

Regarding research quality, the study is evaluated based on Halldórsson and Aastrup (2003)'s four research quality criteria, as explained in Chapter 3.7: credibility, transferability, dependability, and confirmability. Credibility is strengthened through the use of multiple data sources. Insights from internal interviews, external expert interviews, and the literature review show recurring patterns and consistent observations regarding data challenges, organizational alignment and simulation prerequisites. This triangulation supports the overall trustworthiness of the findings.

Transferability is supported by the alignment between the identified challenges at Scania and those described in existing literature concerning global supply chains. The observed issues - data availability and quality, cross-functional misalignment and complexity in decision-making - are not unique to the case company. This suggests that the findings and recommendations may be applicable to other large organizations with similar supply chain characteristics. At the same time, the study is based on a single case, and the results are influenced by Scania's specific organizational context, which limits the extent to which conclusions can be generalized without further validation.

Dependability is ensured by a clearly documented research process. The methodology outlines how data has been collected, analyzed, and synthesized, enabling traceability of the reasoning and findings. However, this criterion is partly constrained by the anonymization of interviewees, which limits full transparency in the empirical material.

Confirmability is affected by the qualitative nature of the study. Interview-based findings may be subject to bias, as they rely on the perspectives of individual respondents. To mitigate this, interview guides are provided in the appendix, allowing the reader to interpret findings in relation to the questions posed. In addition, parts of the empirical material, particularly data used in the data availability mapping, are based on internal Scania documents that are subject to confidentiality. This restricts external verification and makes it difficult to fully assess potential bias of the researchers.

9.3.2. Future Research

A natural progression for future research involves scaling the highly abstracted conceptual model into a comprehensive digital representation of the entire RMC Nordic network. Once validated on a larger scale, the framework could also be applied to Scania's other regional control towers, such as RMC Europe and RMC SLA. In accordance with Robinson (2013)'s conceptual modeling framework, which emphasizes the need to balance model complexity with feasibility by strictly defining model boundaries, this study deliberately excluded constrained operational capabilities - such as finite vehicle fleets and driver rest periods. By creating this "far abstraction," the conceptual model focuses solely on the impact of supply base changes. However, Robinson (2013) notes that reducing the level of abstraction and increasing the scope and level of detail is often necessary to enhance a model's operational credibility. Therefore, future simulation research should incorporate these precise operational constraints to better reflect real-world scenarios. Finally, just as Robinson (2013) highlights the importance of carefully selecting what to include and exclude in the problem domain, this study restricted its theoretical boundaries to inbound logistics. To gain a more comprehensive perspective on simulation readiness at RMC Nordic, future research should expand these boundaries to incorporate actual downstream customer demand. This would enable researchers to evaluate how the chain reactions of upstream supply base changes affect the entire logistics network.

Another relevant avenue for future research would be to expand the perspective beyond Scania and investigate simulation readiness across another global manufacturing firm operating in similar industrial contexts. While this thesis provides an in-depth case study of RMC Nordic's inbound logistics organization, it remains unclear to what extent the identified challenges related to data availability, organizational coordination, legacy systems and simulation competence are unique to Scania or representative of broader industry-wide patterns. A comparative case study involving another global manufacturing firm could therefore provide valuable insights into common barriers, enabling factors and differences in how organizations approach simulation-based decision support.

Furthermore, future studies could adopt a broader and less case-specific perspective by examining simulation readiness and simulation usage across several similar companies simultaneously, rather than conducting a deeply embedded analysis of a single organization. Such research could investigate the overall maturity of simulation usage within global manufacturing industries, identify recurring organizational and technical obstacles preventing adoption, and explore the strategic, operational and cultural reasons why some firms actively utilize simulation while others do not. This could contribute to a more generalized understanding of simulation readiness as an organizational capability within complex industrial supply chains.

Lastly, the advent of AI is likely to cause a fundamental shift in the simulation industry. The literature review and external interviews support the choice of an external third party service in this thesis (Interviewees Q_e, R_e, T_e, V_e; (Liotta, 2012; Saisridhar et al., 2024; Chahal et al., 2013)) but external interviewees note that AI could have great impact on simulation practices although they have limited experience using it themselves. Similarly, while much of the simulation literature predates the rise of AI coding, there are multiple papers that see great potential in combining AI and simulation (Saisridhar et al., 2024; van der Zee and van der Vorst, 2005; López-Pintado et al., 2024) making it possible that building your own model in-house could be the right course of action. This choice between AI coding and third party software would be interesting to conduct further research on to understand the potential gains in efficiency, customizability, model accuracy and feasibility of implementation that can be achieved when building simulation models with the use of AI coding tools.

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APPENDIX

Appendix A: Interview Guide – Inbound Logistics and Network Design

Background & Role

1. Can you briefly describe your role and main responsibilities within logistics?
2. How long have you been in this role, and in logistics at Scania?
3. Which parts of the nordic inbound logistics network are you most involved with?
   - Specific production sites?
   - Suppliers?
   - Transport lanes?
   - Cross-docks?
4. What are the main KPIs or performance metrics you are responsible for?

Current Decision-Making Processes

5. When changes happen in the supply base (new suppliers, relocated suppliers, volume shifts), how do you typically learn about them? *Potential topics to cover:*
   - Formal communication channels? Informal?
   - How much advance notice do you usually get?
   - Is the information sufficient for planning?
6. Can you explain what happens when you learn about a planned supply base change:
   - Who do you involve?
   - What analysis do you do?
   - What decisions do you need to make (routes, transport modes, cross-dock usage, inventory policies)?
   - What tools or systems do you use?
7. How much input does logistics/RMC have into supplier selection decisions?
   - Are you consulted before decisions are made?
   - If yes, do you generate estimates that ground the decision in any way?
8. Are there formal processes or forums where procurement and logistics jointly discuss supply base changes?
   - If yes: How do they work? How effective are they?
   - If no: Would such forums be valuable? What would they need to include?

Information Availability & Gaps

9. What data or information do you currently have access to for planning inbound logistics? *Potential topics to cover:*
   - Supplier locations, volumes, lead times?
   - Transport costs, routes, carrier performance?
   - Cross-dock capacities, handling costs?
   - Product characteristics (weight, volume, value)?
10. What information do you need but don't currently have - or don't have in a usable format? *Potential topics to cover:*
    - Supplier-level detail (production schedules, minimum order quantities)?
    - Forward-looking information (planned supplier changes, volume forecasts)?
    - Cost breakdowns (transport, handling, inventory)?
11. Where does the data you use come from?
    - What systems? (ERP, TMS, WMS, spreadsheets?)
    - How often is it updated?
    - How much manual work is required to get it into a usable format?
12. If you wanted to assess the logistics impact of a supply base change BEFORE it happens, what would you need?
    - What data?
    - What tools or models?
    - What involvement from other functions?

Challenges & Pain Points

13. Can you describe a recent situation where a supply base change created unexpected challenges for logistics?
    - What was the change?
    - What went wrong or was difficult?
    - Could it have been anticipated?
    - What would have helped?
14. What are the biggest challenges you face in planning and managing inbound logistics? *Potential topics to cover:*
    - Lack of visibility?
    - Lack of advance notice?
    - Coordination with procurement?
    - Data quality or availability?

- Complexity of the network?

15. Are there decisions made by other functions (procurement, production) that significantly affect your work, but where you feel logistics input is missing or insufficient?

Simulation & Decision Support

16. Do you currently use any tools or models to evaluate different logistics scenarios or network configurations?
    - If yes: What tools? How are they used? How effective are they?
    - If no: Have you wished for such tools? What would they need to do?
17. Have you heard of or worked with simulation-based decision support (e.g., modeling material flows, evaluating "what-if" scenarios)?
    - If yes: In what context? What was your experience?
    - If no: Does the concept sound useful for your work?
18. If you could use a simulation model to test how a supply base change would affect logistics performance (costs, lead times, service levels), what would that enable you to do differently?
19. What do you think would be the main barriers or challenges to implementing such a capability?
    - Data availability?
    - Technical skills?
    - Organizational alignment?
    - Time and resources?

Organizational & Process Questions

20. Who has the final say on decisions about inbound logistics network design (routes, cross-dock usage, carrier selection)?
    - Is this decision-making centralized or distributed?
21. How well-aligned do you feel logistics and procurement are in terms of goals, priorities, and ways of working? *Potential topics to cover:*
    - Do you feel you're working toward the same objectives?
    - Are there conflicts or trade-offs that are difficult to resolve?
22. If you could change one thing about how supply base or network design decisions are made at Scania, what would it be?

Closing Questions

23. Is there anything important about logistics planning, supply base changes, or decision-making processes that we haven't discussed but you think we should know?
24. Are there other people in logistics, procurement, or elsewhere at Scania who you think we should talk to for this study?
25. Would you be interested in seeing the results of this study or participating in a follow-up workshop where we present our findings and proposed framework?

Appendix B: Interview Guide – Procurement

Background & Role

1. Can you briefly describe your role and main responsibilities within Global Procurement?
2. How long have you been in this role, and in procurement at Scania?
3. Which product categories, commodities, or supplier segments are you most involved with?
4. What are the main KPIs or performance metrics you are responsible for?
    - Cost savings? Supplier performance? Risk? Sustainability?

Current Decision-Making Processes

5. Walk me through how supplier selection or supply base change decisions are made:
    - What triggers these decisions? (cost reduction, capacity, risk, new products?)
    - Who is involved in the process?
    - What criteria do you evaluate? (price, quality, lead time, location, capabilities?)
    - What tools or frameworks do you use?
6. When evaluating a new supplier or sourcing strategy, how much do you consider logistics implications? *Potential topics to cover:*
    - Transport costs? Lead times? Network complexity?
    - Do you have tools or models to estimate these impacts?
    - Do you consult with logistics/RMC? At what stage?
7. How much advance notice or visibility does logistics/RMC typically have into planned supply base changes?
    - When and how do you communicate these changes?
    - Is the communication formal or informal?
    - Is it sufficient, in your view?
8. Are there formal processes or forums where procurement and logistics jointly discuss supply base changes?
    - If yes: How do they work? How effective are they?
    - If no: Would such forums be valuable? What would they need to include?

Information Availability & Gaps

9. What data or information do you currently have access to when making supplier selection decisions? *Potential topics to cover:*
    - Supplier capabilities, costs, lead times?

- Historical performance data?
- Demand forecasts, volume projections?
- Logistics costs or lead time impacts?

10. What information do you need but don't currently have - or don't have in a usable format? *Potential topics to cover:*
    - Total cost of ownership (including logistics)?
    - Lead time variability or reliability data?
    - Impact of sourcing decisions on network structure or performance?
11. What information do you provide to logistics, and in what format?
    - Supplier locations? Expected volumes? Lead times?
    - How far in advance?
    - Is this information sufficient for logistics planning, in your view?
12. If you wanted to assess the total supply chain impact of a supplier change BEFORE making the decision, what would you need?
    - What data?
    - What tools or models?
    - What involvement from other functions?

Challenges & Pain Points

13. Can you describe a recent situation where a supplier selection or supply base change created unexpected challenges or outcomes?
    - What was the change?
    - What went wrong or was difficult?
    - Could it have been anticipated?
    - What would have helped?
14. What are the biggest challenges you face in managing the supplier base and sourcing strategy? *Potential topics to cover:*
    - Balancing cost vs. risk?
    - Coordination with logistics or production?
    - Data quality or availability?
    - Complexity of the supply base?
15. Are there decisions made by other functions (logistics, production, sales) that significantly affect your work, but where you feel procurement input is missing or insufficient?

Simulation & Decision Support

16. Do you currently use any tools or models to evaluate different sourcing scenarios or supplier configurations?
    - If yes: What tools? How are they used? How effective are they?
    - If no: Have you wished for such tools? What would they need to do?
17. Have you heard of or worked with simulation-based decision support (e.g., modeling supply chain impacts, evaluating "what-if" scenarios)?
    - If yes: In what context? What was your experience?
    - If no: Does the concept sound useful for your work?
18. If you could use a simulation model to test how a supply base change would affect total supply chain performance (costs, lead times, service levels, resilience), what would that enable you to do differently?
19. What do you think would be the main barriers or challenges to implementing such a capability?
    - Data availability? Technical skills? Organizational alignment? Time and resources?

Organizational & Process Questions

20. Who has the final say on supplier selection and supply base structure decisions?
    - Is this decision-making centralized or distributed?
    - How much input does logistics have?
21. How well-aligned do you feel procurement and logistics are in terms of goals, priorities, and ways of working? *Potential topics to cover:*
    - Do you feel you're working toward the same objectives?
    - Are there conflicts or trade-offs that are difficult to resolve?
22. If you could change one thing about how supply base or sourcing decisions are made at Scania, what would it be?

Closing Questions

23. Is there anything important about supplier selection, supply base strategy, or decision-making processes that we haven't discussed but you think we should know?
24. Are there other people in procurement, logistics, or elsewhere at Scania who you think we should talk to for this study?
25. Would you be interested in seeing the results of this study or participating in a follow-up workshop where we present our findings and proposed framework?

Appendix C: Interview Guide – External Parties

Background & Experience

1. Can you briefly describe your role and your organization's work in supply chain simulation?
2. How long have you been working with supply chain simulation and decision support tools?
3. What types of clients do you typically work with?
    - Industries? Company sizes? Geographic regions?
4. What are the most common use cases or decision problems your clients use simulation to address?

Data & Information Requirements

5. What are the essential/typical data requirements for simulating an inbound logistics network?
    - Network structure? Flows? Costs? Lead times? Variability?
    - What level of granularity is needed?
    - Specific products?
    - Weight of products?
    - Dimension of products?
6. How do you typically collect essential data?
    - Sensors?
    - Barcodes?
    - Scripts?
7. How do you handle situations where clients don't have perfect data?
    - What are acceptable compromises or approximations?
    - How do you prioritize data collection efforts?
8. What data sources do your clients typically use?
    - ERP, TMS, WMS systems?
    - Manual data collection?
    - External data (suppliers, carriers)?
9. How do you help clients integrate data from multiple systems or functions?
    - What technical approaches work well?
    - What organizational challenges do you encounter?

Simulation Implementation & Success Factors

10. Based on your experience, what makes a simulation project successful? *Potential topics to cover:*
    - Technical factors (data, tools, modeling)?
    - Organizational factors (sponsorship, alignment, ownership)?
    - Process factors (integration into decision-making)?
11. Can you describe a particularly successful simulation implementation you've been involved with?
    - What was the business problem?
    - How was simulation used?
    - What made it successful?
    - What were the key outcomes?
12. Can you describe a simulation project that failed or did not deliver expected value?
    - What went wrong?
    - Was it a technical issue, organizational issue, or something else?
    - What lessons did you learn?
13. In your experience, what are the most common barriers or challenges companies face when trying to implement simulation-based decision support? *Potential topics to cover:*
    - Data availability and quality?
    - Lack of technical skills?
    - Organizational resistance or misalignment?
    - Lack of sponsorship or buy-in?
    - Integration into existing processes?
14. How important is organizational readiness vs. technical capability for simulation success?
    - What does organizational readiness look like in practice?

Organizational Prerequisites

15. In your experience, who should "own" simulation capability within a company?
    - Logistics? Procurement? Central planning/analytics?
    - What responsibilities and authority do they need?
16. How important is cross-functional collaboration for simulation-based decision support?
    - What mechanisms or structures have you seen work well (e.g., cross-functional teams, steering committees)?

- How do you get different functions (procurement, logistics, production) aligned around simulation insights?

17. How do you ensure that simulation results actually influence decisions?
    - How do you embed simulation into decision-making processes?
    - How do you build trust and credibility with decision-makers?
18. What role does senior leadership play in successful simulation implementations?
    - How important is executive sponsorship?
    - What does good sponsorship look like?

Tools, Technologies, & Competencies

19. What simulation tools or platforms do you recommend for logistics network design, and why?
    - What are the trade-offs between different tools?
20. What competencies or skills does a company need internally to effectively use simulation?
    - Modeling/technical skills?
    - Business/domain knowledge?
    - Change management/stakeholder engagement?
21. Can companies successfully use simulation without deep technical expertise, or is external support usually necessary?
    - What can companies realistically do in-house vs. with external help?

Specific Application: Supply Base Changes

22. Have you worked with clients who use simulation to evaluate supply base changes or sourcing strategy decisions?
    - If yes: How is simulation used in that context? What insights does it provide?
    - If no: Do you see potential value in this application?
23. What would be the key prerequisites for a company to be able to simulate the logistics impact of supply base changes?
    - Data? Organizational structures? Processes?

Recommendations & Future Trends

24. If you were advising a company like Scania that wants to develop simulation-based decision support for logistics network design, what would be your top recommendations?

- Where should they start?
- What should they prioritize?
- What pitfalls should they avoid?

25. What trends do you see in simulation technology and practice for supply chain decision support?
    - Digital twins? AI/ML integration? Real-time simulation?
    - How do these trends affect prerequisites and implementation approaches?

Closing Questions

26. Is there anything important about simulation implementation, organizational readiness, or decision support that we haven't discussed but you think we should know?
27. Are there other experts, practitioners, or companies you think we should speak with for this study?
28. Would you be interested in seeing the results of this study when it's completed?