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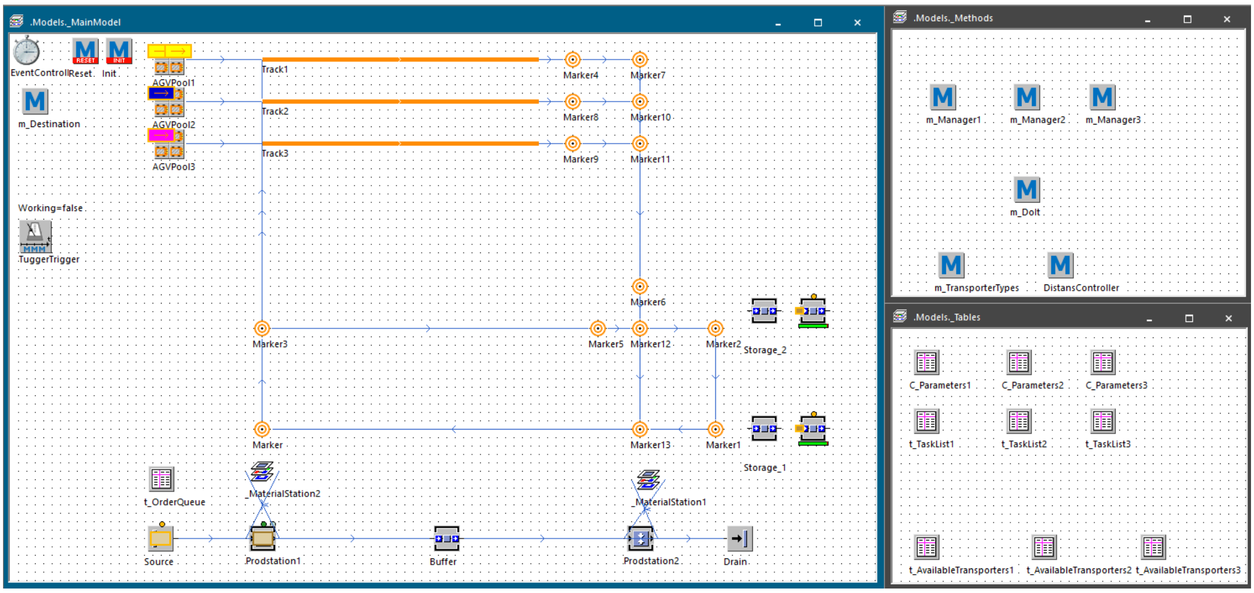

Modelling and Simulation of Transporter Behaviour in Intralogistics Systems

A Data-Driven and Task-Based Control Logic for Standardized Transporter Modeling in Discrete Event Simulation

Master's thesis in Production Engineering

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Cover: Transport behavior test model in Tecnomatix Plant Simulation

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Abstract

Intralogistics systems are essential for enabling efficient material flow in modern manufacturing, yet current discrete-event simulation (DES) approaches often rely on fragmented data and simplified transporter representations, thereby limiting their effectiveness as decision-support tools. This thesis investigates how transporter behavior can be systematically modeled in DES to enable consistent and comparable evaluation of intralogistics solutions. The study is conducted as a qualitative case study at Volvo Car, combining a literature review, semi-structured interviews, and simulation modeling in Tecnomatix Plant Simulation. The results show that standardized, externalized input data support the development of generic, reusable simulation models, thereby reducing manual effort and improving comparability. Furthermore, transporter behavior can be effectively represented using a task-based control logic approach, enabling different transporter types to be implemented within the same framework. The findings indicate that combining standardized data structures with generic model design and behavior logic can enhance reusability and decision support in intralogistics simulation. This thesis provides a foundation for future data-driven and automated DES applications for intralogistics.

Keywords: Discrete Event Simulation, Intralogistics, Data Management, Automated Model Generation, Generic Simulation Model, Automotive Industry

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List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AGV	Automated Guided Vehicles
AMR	Autonomous Mobile Robots
DELS	Discrete-Event Logistics Systems
DES	Discrete Event Simulation
DEVS	Discrete Event System Specification
ERP	Enterprise Resource Planning
GDM	Generic Data Management
MAS	Manufacturing Automation System
MES	Manufacturing Execution System
TPS	Tecnomatix Plant Simulation
VCC	Volvo Car Corporation
VCLAS	Volvo Common Logistics and Sequencing System
VCT	Volvo Car Torslanda

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1
Introduction

This chapter provides background on the research topic and its context. It also presents the thesis purpose, outlines the research questions, and defines the thesis scope and limitations.

1.1 Background

Intralogistics systems are an important part of modern manufacturing, enabling the internal flow of materials between storage areas, production lines, and assembly stations. In large-scale production systems, particularly within the automotive industry, efficient intralogistics is essential for maintaining high throughput, minimising downtime, supporting increasingly flexible production strategies, and remaining competitive in the market. As production systems evolve, internal logistics must adapt accordingly, placing greater demands on system design, control, and planning [1].

Within intralogistics, transporters of goods play a crucial role, as they enable the movement of materials and directly influence system performance, flow efficiency, and operational flexibility. Different types of intralogistic transporters, such as Automated Guided Vehicles (AGVs), tugger trains, and forklifts, operate under distinct navigation rules, task allocation strategies, and interactions with surrounding traffic and infrastructure. As a result, their operational behaviour varies between transporters. Understanding these behavioural differences is critical when designing, configuring, or scaling intralogistics systems, especially in greenfield environments where multiple transporter types [2].

In greenfield environments, DES has been extensively used for production system analysis, particularly for production flow and capacity [3]. However, while it is widely used in production planning, DES is less commonly applied to intralogistics systems. Although the method offers capabilities for representing dynamic interactions and overall system behaviour, it has not yet been fully explored in the intralogistics context. In particular, limited to representing transporter behaviour, traffic interactions, and decision making across entire transporter fleets.

In parallel, the manufacturing industry is transforming through increased digitalisation, system integration, AI, and data availability, driving the transition from Industry 4.0 towards Industry 5.0. In this context, simulation and virtual commissioning are increasingly used to support planning, validation, and operational decision-making of production systems [4]. Simulation software is extra valuable in early design phases, such as greenfield factory planning, where rapid prototyping of alternative layouts and control strategies can significantly reduce development risk and time. However, the reliability and usefulness of such simulation-based analyses are highly dependent on the quality, structure, and availability of input data [5], [6].

A recurring challenge is that many internal logistics simulations are developed as simplified, single-flow models that focus on isolated transport processes and do not account for multiple, interacting logistic flows. As a consequence, these models often fail to assess how transporter behaviour influences or is influenced by surrounding traffic, shared resources, or the broader logistics system. Furthermore, input data for internal logistics is frequently fragmented across departments and information systems, making data gathering time-consuming and difficult [7]. Behaviour information for transporters, such as routing logic, priority rules, traffic constraints, and decision-making strategies, is often temporary rather than represented in standardised, reusable data structures.

The absence of a standardised approach to modelling transporter behaviour results in project-specific simulation models with limited transparency, reusability, and comparability [8]. This not only complicates systematic evaluation of alternative transporter technologies and control strategies, but also leads to repeated modelling efforts across projects. These limitations reduce the effectiveness of DES as a decision-support tool, slowing model development and limiting its ability to support strategic planning, including fleet sizing, layout changes, and comparisons of result.

From both industrial and academic perspectives, these challenges highlight the need for generalised, structured approaches to modelling transporter behaviour in DES environments. Standardised behaviour descriptions and data representations have the potential to improve model realism, support rapid prototyping of alternative system designs, and enable consistent comparison across simulation. Such approaches are particularly important in large manufacturing systems, where long-term planning decisions depend on reliable simulation results and changes to intralogistics systems are costly to implement in practice [9].

To examine these challenges in a realistic industrial setting, this study is situated in the automotive manufacturing sector at the Volvo Cars Torslanda (VCT) production facility. This illustrates a large-scale industrial environment with complex intralogistics and diverse transport systems. This provides an opportunity to investigate how real transporter behaviour data can be structured and represented in DES models. While this study is based on an empirical case, the proposed approach is intended to be applicable beyond the specific context and to support broader research in intralogistics simulation and data-driven modelling.

1.2 Purpose & Aim

The purpose of this thesis was to develop a standardised behaviour database for intralogistics transporters that captures transporter-specific characteristics, enabling systematic comparison and evaluation of transporter alternatives. The motivation behind this work is the increasing complexity of intralogistics systems and the lack of structured methods for evaluating different transporter solutions and operational performance during system design and decision-making processes. Without behavioural transporter models, selection often relies on simplified assumptions and limits the accuracy of analyses, which reduces decision support quality.

The aim was to develop transporter models in the DES software and integrate their behaviour with internal operational constraints and decision-making strategies, enabling more realistic and data-driven simulation of intralogistics operations.

1.3 Research Question

The purpose of this thesis was to develop a standardized behavioral database for intralogistics transporters and investigate how transporter-specific behavior and operational logic can be represented in DES. The study further aimed to integrate transporter behavior with internal operational constraints and decision-making strategies to support more consistent, reusable, and comparable simulation models for intralogistics systems. This thesis was structured around the following research questions:

- *RQ1: How can a standardized database for intralogistics and transporter behavior modeling in discrete event simulation enable consistent and comparable evaluation of different intralogistics transporter solutions?*

- *RQ2: How can facility specific transporters and intralogistic systems and real-time dispatching be implemented in discrete event simulation to represent real-world transporter behavior?*

1.4 Delimitations

This thesis was conducted within a limited time frame of approximately five months, which constrained the scope of data collection, model development, experimentation, and analysis. Furthermore, this thesis was limited to transporter types currently in operation or future use at the Volvo Car Torslanda plant. The scope was constrained by the availability and accessibility of data for the different transporter types.

As the study relied partly on interviews with company employees, the availability of key personnel was occasionally limited by workload and operational priorities, which affected the depth of the data collected. In addition, the data used to define the model behaviour were specific to the studied production environment, and the results may therefore not be fully transferable to other manufacturing facilities without adjustments to local conditions and operating parameters.

2

Theoretical Background

This chapter presents the theoretical background for this thesis and establishes the conceptual foundation for understanding the research topic. It provides an overview of key subjects related to intralogistics systems and their role within the automotive manufacturing sector. This chapter also introduces DES as a modeling approach for analyzing logistics and production systems. On the topic of simulation modeling, relevant aspects such as input data management and data structuring are included. The chapter also introduces the Discrete Event System Specification (DEVS) and Discrete Event Logistics Systems (DELS) frameworks, which support the standardized, structured representation of logistics systems.

2.1 Logistic in the automotive sector

Logistics, or supply chain management, can be broadly described as "management of inventory both in motion and at rest" [10]. In the automotive sector, supply chain management integrates a wide range of business activities. The automotive logistics includes the management of warehousing, manufacturing processes, transportation systems, suppliers, and supporting facilities. All these functions support the transformation of goods and services from the raw material into finished vehicles delivered to the end customer [11].

Efficient logistics management has become increasingly critical to the automotive industry competition. This has become particularly critical during crises, such as the COVID-19 pandemic and the war in Iran, which have exposed vulnerabilities in global supply chains and disrupted both material and information flows. In a highly competitive and globalized market, the ability to flexibly manage materials and information is therefore a key factor for maintaining future competitiveness[11].

2.1.1 Internal logistic transporters

Internal logistics includes the movement of goods and warehousing management within a manufacturing environment to optimize production efficiency and avoid disruptions to the production flow [12]. An important part of internal logistics is the use of transporters, which move goods from one location to another, ensuring that materials, components, or finished products arrive at the right place at the right time. The choice of transporters can vary significantly between companies and factories, depending on factors such as layout, production volume, and level of automation. Internal logistics role include the planning and management of transporters such as AGVs, warehouses, conveyors, and other material handling and transportation systems. By reviewing and managing effective internal logistics, it is possible to increase production productivity and reduce operational costs. Additionally, it can also increase flexibility, reduce the risk of delivery delays, and give a better overview. To achieve these positive results, a digital infrastructure is suggested to effectively control the flow of information [1].

2.2 Discrete Event Simulation

DES is a modeling approach in which the state of a system changes only at discrete points in time and as a result of specific event. Such an event can be the arrival of entities, the start or completion of a task, or changes in resource availability. Between these events, the system state remains unchanged. DES is commonly used to model complex, dynamic systems, such as production systems and logistics flows. DES is widely used in manufacturing systems to evaluate alternative scenarios without disrupting the existing production and has also been applied in logistics, healthcare, and construction [13].

To fully understand and analyze a system using DES, the purpose of the simulation study must be defined, as it determines which aspects of the system are of interest and therefore which elements. The main elements of a DES include entities, activities, states, and events. An "entity" represents the object of interest within the system, such as a product, vehicle, or piece of information. Element "activity" describes the time during which the system state remains unchanged, such as transportation, processing, or waiting. The system "state" is defined by a set of state variables that capture its condition at any given moment. An "event" is an instantaneous occurrence that can cause a change in the system state, such as the completion of an activity or the arrival of an entity[13]. Events and activities that originate within the system and influence its behavior are referred to as "Endogenous" [13].

DES can be implemented using software tools that enable simulation techniques to create digital models of real production systems. These tools allow users to represent and analyze production and logistics systems in a virtual environment. Several simulation software utilize DES, including TPS, Visual Components, and FlexSim [14].

2.2.1 Tecnomatix Plant Simulation

TPS is developed by Siemens and is a software used to design and evaluate manufacturing and logistics systems. It enables the virtual recreation of production environments, making it possible to study how materials move and how operations perform with DES. It enables many features, for example, the identification of system constraints, the analysis of energy usage, proof of concept, and the testing of production scenarios. Furthermore, simulation analysis can support decision-making by reducing the need for costly physical experiments and investments, thereby minimizing both operational risks and investment costs [15]. By exploring different scenarios, it is possible to evaluate performance before implementing changes in real life [16]. TPS is a well established simulation tool at VCC and across many other manufacturing industries, and is therefore selected as the simulation software used for this thesis.

To reduce the time and effort required to build a simulation model in Plant Sim, predefined objects and functions can be inserted using a drag-and-drop. The model can be visualized in both 2D and 3D to enhance understanding and analysis. TPS uses a programming language called SimTalk, which allows custom logic through methods that can be applied in objects. This provides flexibility for defining complex behaviors and controlling system operations [17]. The main standard objects used in this thesis include:

- **Frame:** Is the main workspace in TPS where the model is built. It can also contain subframes, allowing the model to be divided into smaller sections for better structure and organization [18].

- **Method:** Is a workspace for writing and executing SimTalk code, allowing users to define custom logic and control[18].

- **DataTable:** Is a list consisting of rows and columns, where each cell can store different data types[18].

- **Transporters:** Is an object used to model vehicles that transport materials. It can move along tracks or "freely", and load, carry, and unload items such as parts or containers[18].

- **AGVPool:** is used to create and manage AGVs that move freely within the system without fixed routes. It navigates using Nodes and adapts AGVs paths dynamically [18].

- **Marker:** are the Nodes that guide AGVs along paths in the simulation. It allows Transporters to navigate by setting specific positions and directions [18].

- **Part:** represents a workpiece, also known as a Moving Unit (MU). It does not have its own transport capability but can instead be processed, stored, and transported by other objects [18].

- **Buffer:** used to temporarily store MUs between processing stations in a material flow and releasing them according to predefined conditions or rules [18].

2.3 Input Data Management in DES

DES projects are highly dependent on the availability and quality of input data. Input data management is the process of identifying, collecting, transforming, validating, and documenting the data required for the simulation model. This also includes converting raw data into quality input parameters that represent the real system. Despite its importance, several studies have shown that input data management is one of the most time-consuming phases of a simulation project, accounting for up to 10–40% of the total time [19]. This is largely because data is often collected for project-specific purposes and is rarely reused across different simulation projects. As a result, it limits comparability and credibility between projects [20].

One approach to speeding up input data management is to automate data collection via databases and to structure simulation input data in external files [6]. Simulation input data can be stored and exchanged using various file formats, such as XML, JSON, Excel, and CMSD. A common challenge with file structuring is ensuring a shared understanding of the underlying parameters and their meanings. This challenge can be addressed by using standardized building blocks and data models, which enable understanding of parameters. Standardization also improves interoperability, consistency, and reusability of simulation data[21]

2.4 Standardization efforts in DES

There are several frameworks for structuring simulation input data to improve its meaning, usability, and reuse across different systems and stakeholders. These frameworks provide standardized ways of representing system entities, processes, resources, and relationships, which reduces ambiguity in data interpretation. By using frameworks for data structures, they support interoperability between simulation tools, databases, and industrial platforms. They also improve data consistency and make simulation data easier to reuse in different models and applications [22].

In the context of DES, DEVS provides a formal framework for organizing system information. DELS defines a generic system modeling framework for production and logistics systems by identifying common structural and behavioral elements across domains such as manufacturing plants, warehouses, material-handling systems, and supply chains. As a result, DEVS enable consistency in storage, exchange, reuse, and comparison of simulation data format [23]. While DEVS is for manufacturing systems, DELS conceptualizes system information around logistics. DELS builds on the DEVS structure but uses logistics-specific abstractions to organize data on material flows and resources [24].

From a data management perspective, DELS structure enables a clear definition of input parameters, uniform data presentation, and improved readability of simulation models [25]. The approach is grounded in model-based systems engineering, in which logistics systems are described using a fixed set of generic elements, which are:

- **Products:** Products represent the items that flow through a logistics system. This includes raw materials, parts, subassemblies, finished goods, and loads. Products are discrete and may carry attributes describing their type, state, and quantity as they move through the system [25].

- **Processes:** Processes describe transformations or handling steps applied to products. These processes capture activities such as manufacturing operations, storage, consolidation, sorting, loading, unloading, and transportation-related actions that change the state or location of products [25].

- **Resources:** Resources are the system elements that perform processes. This includes machines, workstations, vehicles, conveyors, storage locations, and human operators. Resources are characterized by their capabilities, capacities, and availability, which constrain how and when processes can be executed [25].

- **Operational control:** Operational control elements define the decision logic governing system behavior. These elements specify rules for sequencing, routing, dispatching, scheduling, and prioritization, and determine how products and resources are coordinated during system operation [25].

- **Networks:** Networks describe the structural connectivity of the system. They define how resources and processes are linked spatially or logically, typically using nodes and connections to represent layouts, transport routes, and material flow paths [25].

- **Flows:** Flows represent the movement of products through the network and between processes and resources. They formalize material and order movement relationships and provide the linkage between static system structure and dynamic system behavior [25].

By formalizing these elements using DES, it becomes independent of any specific simulation tool and provides a consistent, reusable system description that can serve as a basis for generating DES models [26].

Another important framework is Asset Administration Shell (AAS), which is a standardized knowledge structure used to create a digital representation of a physical asset and to communicate its characteristics, functionality, and behavior. The concept AAS was introduced in 2019 by the German industry and researchers in "Plattform Industrie 4.0". The primary objective is to support industrial digitalization by enabling structured, interoperable, and data exchange across different systems[27].

An AAS-bas consists of a set of submodels, where each submodel represents a specific aspect of the asset. These submodels can describe characteristics, properties, operational states, parameters, measurement data, energy use and capabilities. Submodels are commonly standardized using predefined templates, ensuring consistency and interoperability. This modular organization technique supports standardization and reusability. This allows different aspects of the asset to be utilized independently, depending on the context[28].

2.5 Generic model building for DES

Automated model building represents a method of working in DES where the simulation model is constructed using generic, reusable logic rather than manually hard-coded objects and connections. In this approach, the generic simulation parses standardized input data from external sources, such as for example JSON, XML, or Excel. These external files contain system-specific parameters, such as example coordinates, routing, cycle times, or transporter properties, while the underlying simulation code maintains the general logic. By separating simulation logic from system-specific data, the same DES architecture can be reused by updating the external input. This modularity facilitates the development of more flexible, scalable, and reusable simulation models, ultimately supporting the automated generation of complex simulation structures [29].

3

Methodology

This chapter presents the methodology used in this thesis and describes the overall research structure. It follows an empirical research process from data collection to analysis and conclusions. The chapter describes the selected research methods, including the literature review, interview study, and simulation modeling approach, and explains how the simulation model was developed, verified, and validated.

3.1 Empirical Research

This thesis followed an empirical research framework that provided an overall structure for the work. The study is designed as a qualitative, empirical case study with simulation-based modeling analysis [30]. The first step in the empirical research process was to define the research objective by formulating the research questions and specifying the thesis scope and time frame. This step established the overall direction of the thesis and sets the delimitation [30]. The second step was to review literature and theory related to intralogistics systems, transporter behavior, discrete-event simulation, and data management. A structured thematic literature review was conducted to understand the current state of research, identify existing work and limitations, and provide a theoretical foundation for the thesis [30].

The third step was to define the research strategy and data collection methods. Given that the research is a case study at VCC and the need for capturing tacit knowledge, interviews were selected as the primary data collection method. Semi -structured interviews were conducted with VCC staff to collect qualitative data on transporter behavior, decision-making processes, intralogistics, and operational constraints at VCT. In addition, a software review of Tecnomatix Plant Simulation (TPS) was performed to understand how behavioral logic could be implemented in the simulation model [30].

The fourth step was data analysis and result structuring. The qualitative data were organized using thematic analysis. The qualitative data collected through interviews and a literature review formed the basis for standardizing transporter behavior and translating it into simulation inputs for modeling. The last step was to report findings, limitations, and also recommendations for further [30].

3.2 Literature review

To gather the theoretical foundation needed to answer the research questions, a narrative literature review was conducted. Narrative literature reviews follow a flexible and iterative process rather than a standardized protocol. The method had four key steps: identifying relevant literature, selecting and organizing key studies, generating themes from the findings, and evaluating contributions for research gaps [31].

Literature was identified through searches of scientific databases, including Scopus and Google Scholar, using keywords. The keywords were derived from the research questions and included terms such as *standardized database, intralogistics, transporter behavior, discrete event simulation, intralogistics management,* and *dispatching.* To broaden the search, relevant synonyms and related concepts were also used, such as *behavior modeling, inbound logistics, and decision-making strategies in intralogistics transport systems.* To narrow down the search, keywords were combined using Boolean operators [32]. An example of a search string, "*intralogistics* AND *discrete event simulation*," was used in the scientific databases. The selected literature was analyzed using a six-step thematic analysis and followed an iterative process of familiarization with the data, generation of initial codes, searching for themes, reviewing themes, defining and naming themes, and reporting the themes, and is illustrated in Figure 3.1 [33].

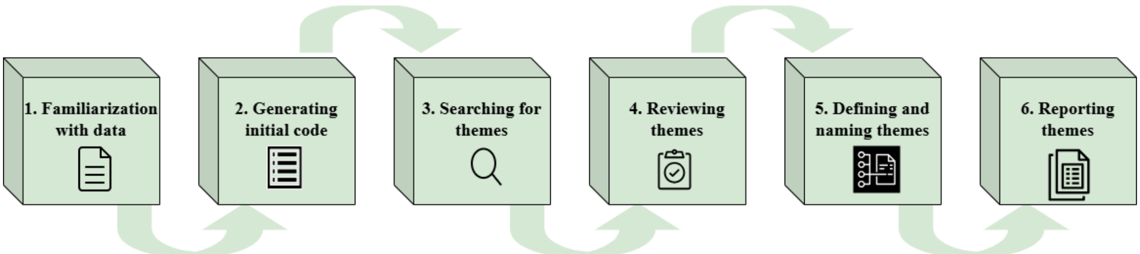

Figure 3.1: 6 steps of thematic analysis

A table of the keywords used is shown in Table 3.1. To ensure the selection of relevant literature, explicit inclusion criteria were defined. Only publications written in English were considered to ensure consistency in interpretation. The selection was limited to studies published after 2000 to ensure relevance to the development of DES and intralogistics systems. Lastly, all sources were required to align with the study's aim and research questions.

Table 3.1: Keywords used for the literature search

Category	Keywords
Data Management & Data Structures	*data management, input data management, standardized data, data structures, data collection, data extraction, automated input data management*
Simulation & Modelling	*discrete event simulation, data-driven modeling, generic simulation models, modular simulation, standardized simulation*
Automated Model Generation	*automated simulation model, data-driven simulation, automatic simulation model generation (ASMG)*
Intralogistics & Transport Systems	*intralogistics, inbound logistics, transporter behavior, transporter solutions, dispatching rules, control logic*

The inclusion criteria were applied through an eligibility screening process for systematic reviews, as illustrated in Figure 3.2 [34]. The screening was conducted in successive stages, including title, abstract, and full text screening, where each article was evaluated against the predefined criteria. This structured approach enabled transparent, consistent evaluation of the literature, ensuring that only relevant literature was included.

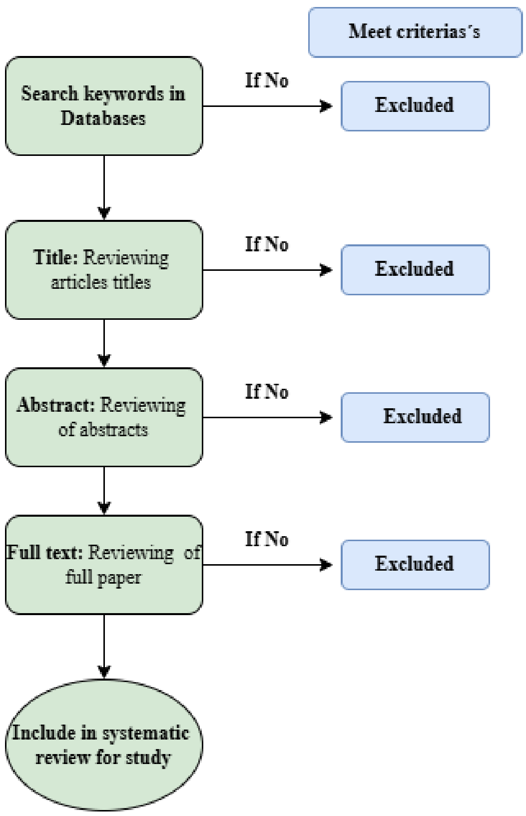

Figure 3.2: Flowchart of eligibility screening process

For the selected paper, relevant information was extracted systematically, with the initial search and the extracted information documented in a separate document. The included papers were then categorized into themes using Microsoft Excel for organization and comparison of findings [35]. The literature review establishes the theoretical foundation of the study while also highlighting current research and existing gaps. The theme findings are presented in the chapter 4.1.

3.3 Qualitative study

The interview questions were developed through a structured and iterative process. First, a literature review of transporter behavior, intralogistics systems, and DES was conducted to establish a knowledge base for the research field. A review of TPS was also done to gain a foundational understanding of its functionality and typical use cases for internal logistics.

The purpose of the interview was to identify the data required to simulate the transporter. Additionally, the interview also aimed to provide insights into how transporters are selected in different situations at VCC. All participants were asked for consent to record the interview to enable a more thorough review, and all recordings were subsequently transcribed. The interviews were semi-structured to collect quantitative data, enabling comparisons between transporter types, and to allow flexibility to ask follow-up questions based on participants responses [36]. Interviews were conducted face-to-face and online in the preferred work language.

The interviews were conducted with key personnel at VCC and were identified with the help of a VCC supervisor, to gather insights across multiple areas of expertise at the VCC Torslanda facility. The interviews were selected from two main organizational groups. In the production department, the focus was on simulation engineers working with DES, and the logistics department consisted of internal logistics experts. Subsequently, a snowball sampling approach was used, in which interview participants were asked to suggest additional individuals relevant to the study [37, 38]. Interviews were conducted until data saturation was reached [39], meaning that no new information emerged and that the challenges described were consistent across interviews. An additional signal of saturation was that participants recommended people who had already been interviewed [40].

3.3.1 Qualitative Data Analysis

Thematic analysis was applied to analyze the data collected from the interviews. The interviews were first transcribe the verbal interview data to enable a familiarization with the material. This process supported an initial understanding of the interviews content and context [41]. The interview analysis followed the six step process of thematic analysis presented in the literature review and illustrated in Figure 3.1. The transcribed data were systematically reviewed and grouped into initial categories. This enabled the identification of patterns within the data [41]. The final step was to review and refine the identified themes. During this phase, themes were examined for relevance in relation to the research objectives[41]. The refined themes were then structured into a developed Expectation matrix. This matrix served as an input for the development of the simulation model [42].

3.4 DES Modeling

A generic transporter behavior model is first developed and subsequently implemented in a DES environment to test and evaluate transporter behavior. The simulation model captures decision-making logic, movement rules, and interactions with traffic regulations under various control strategies and scenarios. The purpose of the simulation model is to provide a standardized, generic framework for implementing transporter behavior across different transporter types within DES. Model development, verification, and validation follow the first seven steps of Banks simulation methodology [13], ensuring a systematic development process and a realistic representation of transporter behavior. An overview of the methodology is presented in Figure 3.3.

In accordance with Banks Step 3 (Model Conceptualization) [13], the real-world transporter system is abstracted into a conceptual model consisting of logical rules and relationships that describe transporter behavior. The conceptualization focuses on identifying the essential system components while avoiding unnecessary complexity.

Step 4 (Data collection) was conducted in parallel with model conceptualization, consistent with Banks methodology [13]. Qualitative data were primarily gathered through expert interviews, providing insights into transporter behavior, operational rules, and decision-making processes in real-world logistics systems. In addition, supporting data such as general operational rules, were obtained from existing databases within the organization. This approach ensured that the behavioral logic embedded in the model reflected operational reality, even when detailed quantitative datasets were unavailable. The collected data were continuously reviewed and refined during model development to resolve inconsistencies and ensure alignment between the conceptual model and real-world behavior.

Following Banks Step 5 (Model translation) [13], the conceptual model was translated into an operational simulation model implemented in TPS. The transporter behavior logic was coded to represent task creation, task handling, movement, decision-making rules, and interactions with traffic infrastructure within the DES environment. During translation, the focus remained on maintaining conceptual accuracy while ensuring simplicity and modularity. The implementation allows transporter behavior models to be reused and adapted across different transporter types and simulation scenarios.

In accordance with Banks step 6 (Verified), the simulation model was verified to ensure it performs as intended and that the implemented transporter behavior logic executes correctly. Verification concerned the correctness of decision-making rules, movement logic, and interactions with traffic regulations within the DES environ-

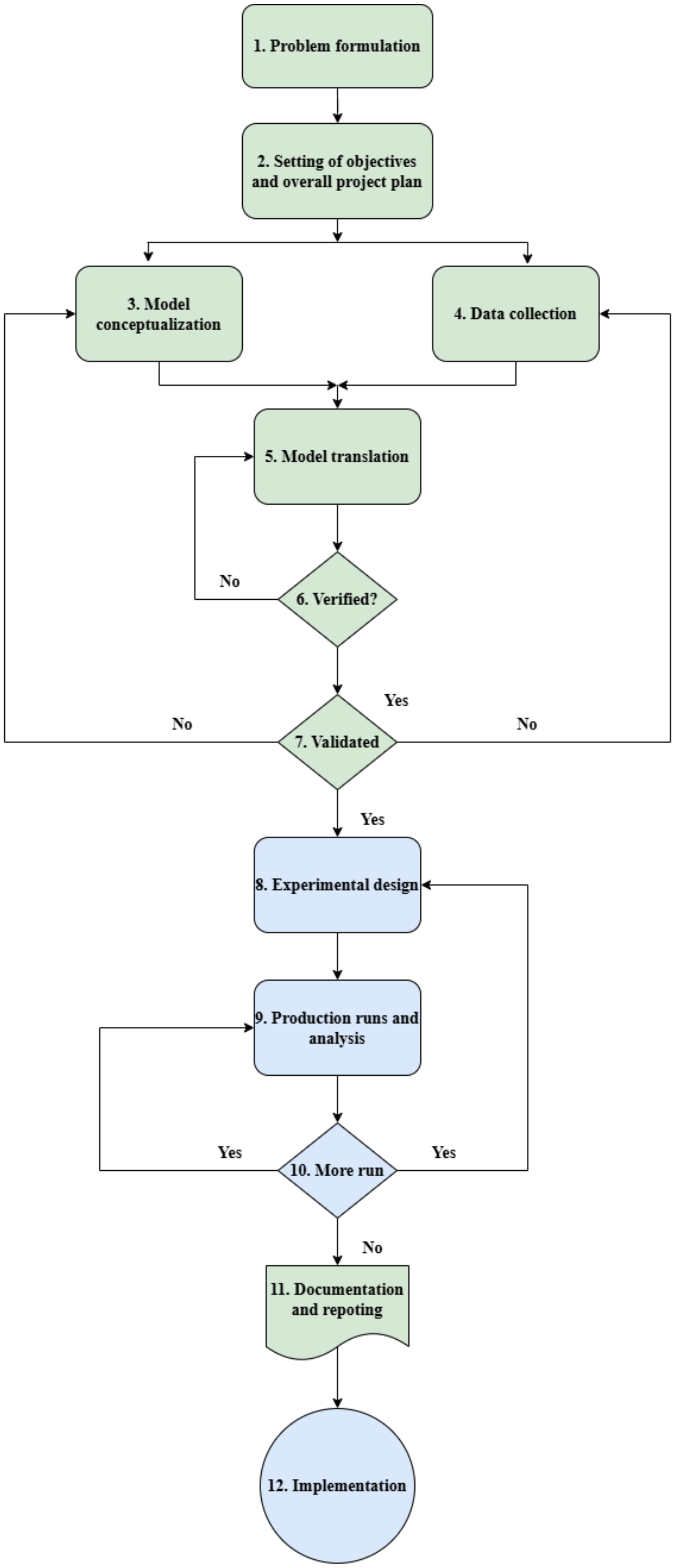

Figure 3.3: Banks methodology

ment. Verification was conducted as a continuous activity throughout model development, rather than as a separate final step [13, 43]. During development, transporter behavior in the simulation was repeatedly inspected and compared with qualitative descriptions of real-world operations obtained through expert interviews. This included assessing transporter responses across varying scenarios to ensure logical consistency and adherence to rules.

Due to the thesis's conceptual focus, verification did not rely on statistical comparisons of outputs or on finished real-world system data. Instead, verification emphasized internal model consistency, correct rule implementation, and logical behavior across test scenarios, supported by regular supervision and reviews with the thesis VCC supervisor, who has extensive experience in DES modeling. This verification approach ensured that the operational model accurately reflects the intended conceptual behavior and functions correctly, which is considered appropriate for exploratory and conceptual simulation studies [44].

Following step 7 (validation), the simulation model was validated to assess whether the conceptual representation of transporter behavior constitutes an acceptable abstraction of real-world intralogistics. According to Banks, validation concerns whether the conceptual model sufficiently represents the real system to be used as a substitute in experimental studies [13].

3.4.1 Validation method

In this study, traditional validation through direct comparison with an existing base system or historical data was not feasible because the work does not aim to replicate a complete real-world system and no comprehensive operational datasets were available.

Instead, validation was performed using qualitative and expert-based methods, including face validity, expert judgment, conceptual model validation, and structured walkthrough [43, 45]. These methods focused on assessing the plausibility, logical consistency, and suitability of the transporters behavior in the simulation model rather than on the accuracy of numerical outputs. Special emphasis was placed on the models ability to represent intralogistics concepts, transporter interactions, and auto-generated simulation structures based on input data, rather than on predictive accuracy or performance optimization.

If unrealistic or inconsistent behaviour was identified during validation, the development process iteratively returned to earlier stages, namely data collection and conceptualisation, for refinement. Once the model was considered sufficiently valid for its exploratory purpose, the study proceeded to step 11, documentation, analysis and reporting.

4

Results

This chapter presents the results of the literature review, highlighting themes that provide the theoretical foundation for this study. This is followed by the results of the qualitative study, which describe the current state of intralogistics and simulation practices at VCT. Based on these insights, a conceptual model for transporter behavior is developed. Finally, a generic simulation model in TPS was designed and implemented.

4.1 Findings from literature review

This section presents the findings from the conducted literature review. A narrative literature review approach was used to identify, analyze, and synthesize relevant studies on the research topic.

Initially, 588 articles were identified based on the selected keywords. These articles were then evaluated in successive stages, including title, abstract, and full-text screening, where each article was assessed against the predefined inclusion criteria [34]. Title screening reduced the number of articles to 97. Abstract screening reduced the selection to 40 articles. Lastly, full-text screening reduced the number of articles to 15. Articles that did not meet the inclusion criteria for language, publication year, or relevance to the study were excluded at each stage. The final set of selected articles is presented in Appendix E.1.

A thematic analysis was then conducted by reviewing and summarizing the content of the selected articles. The 15 articles were then categorized into three main themes. The three main themes identified were:

- Data management for DES
- Generic Simulation Modeling
- Automated Model Generation

These thematic areas were found to be essential for addressing the research questions. A brief description and the key highlights from the reviewed articles are presented below.

4.1.1 Data management for DES

Data collection and data management are widely recognized as major challenges in DES studies. Multiple studies report that data-related activities are time consuming, making simulation results highly dependent on the quality and structure of input data [6, 7, 46]. As a result, improving how data is collected and handled is important for increasing both efficiency and reliability in DES projects. To reduce this effort, the literature emphasizes the use of structured and automated data management processes is a solution.

A systematic approach to identifying, extracting, cleaning, and validating data has been shown to lower modeling effort and improve consistency across DES projects [7, 6]. Several studies also suggest using existing enterprise systems, such as ERP or MES, as primary data sources to ensure that DES models are based on common and up-to-date representation of the system, but this requires a maturity of existing data sources. [6, 47].

Standardization of data formats and structures is frequently highlighted as a key requirement for systematic DES data management. Standardized data reduces tool-specific interpretations, supports interoperability between different DES tools, and enables reuse of data across projects [7, 48, 46]. Common standards, such as CMSD and XML data structures, are therefore proposed to support consistent data exchange and improve transparency in DES modeling [7, 48]. By providing consistent and tool-independent system descriptions, such standardized data structures also enable automated generation of DES models, reducing the need for manual model construction [48, 46, 49, 50, 47].

Several authors propose using intermediary databases or simulation-independent data models to implement data standardization in practice. In these approaches, all simulation information is stored in a centralized data structure that is separate from the DES model itself [6, 51]. This separation allows generic model logic to be reused while the same data structure is applied across simulations, supporting a consistent system representation and comparisons between DES projects [51].

Overall, the literature shows that standardized data structures and intermediary databases play an important role in enabling reuse, transparency, and comparability in DES studies. While various solutions have been proposed, there is broad agreement that consistent evaluation across DES projects depends largely on how system data is structured and managed, rather than on simulation logic alone [46, 49].

4.1.2 Generic modeling

It was identified that generic modeling is a key concept for enabling reusable and time-efficient DES. Generic modeling is briefly described as an approach in which simulation models are designed to be independent of specific systems or scenarios, allowing the same model structure to be reused by simply changing the input data. This is done by separating the simulation model logic from system-specific input data [7].

Data management tools as an important enabler of generic modeling. In particular, the Generic Data Management (GDM) Tool is described as an intermediate layer between production and logistics data sources and DES applications, storing system information independently of the simulation model. By providing standardized input data, the GDM Tool supports automated model generation while maintaining generic, reusable simulation logic. The literature shows that this approach reduces total modeling time compared to traditional data handling methods [52].

It was also identified that a generic modeling framework, called DEVS, and its logistics-oriented extension, DELS. While DEVS provides a domain-independent foundation for reusable DES models, DELS introduces logistics-specific abstractions that structure system information around key logistics concepts, thereby improving model interpretability [23, 25, 53]. Overall, the analysis shows that generic modeling supports consistency, reuse, and comparability across simulation studies.

4.1.3 Automated Model Generation

Component-based automated generation of DES models is widely proposed to reduce modeling time and enable consistent, comparable evaluation of DES projects. The literature emphasizes that dividing systems into standardized, reusable components enables the systematic generation of model structures rather than manual construction, thereby reducing effort and minimizing interpretation differences between models [48, 54, 55].

Several studies show that component-based approaches primarily focus on automatically generating the structure of the DES model. Using predefined architectures or rule-based composition, different intralogistics and production setups can be created from the same set of components, making it easier to compare alternatives under the same modeling assumptions [54, 50, 55].

Automated DES generation also depends on standardized data and model structures. Some approaches use structured operational data, such as ERP data, to automatically generate simulation models via predefined mappings [47]. Other approaches reuse components extracted from existing DES models, enabling the generation of new model variants without rebuilding them from scratch [49]. In logistics applications, standardized descriptions of layouts and processes enable the generation of customized DES models with minimal user input [56].

Different levels of automation are reported in the literature, ranging from semi-automated creation of DES model frameworks to mostly automated generation of complete model variants. Higher levels of automation reduce modeling time and enable the exploration of many system alternatives, but they also require more standardized components and input data [46, 54]. A common limitation is that control and decision logic are usually predefined or parameterized rather than automatically generated, highlighting a trade-off between time savings and modeling flexibility in intralogistics DES models [55, 56].

4.2 Findings from the Qualitative study

This section presents the key findings and insights from interviews with VCT personnel. The results provide an overview of the current state of DES and intralogistics use within the company. In total, 14 interviews were conducted: eight with internal logistics experts, three working in both logistics and simulation, and three with simulation engineers. In addition to the interviews, five VCT shop visits were conducted to observe how transporters operate in practice. A visualization for findings from the qualitative study can be seen in Figure 4.1.

Today, VCT consists of three production facilities, A-, B-, and C-shop (Body in white, Paint, and Final Assembly). Each factory is mostly self-monitored and has over time, developed its own systems for production and logistics data, as well as flow analysis. This has resulted in information being scattered across many different databases, and logistics and production often use different systems for the same data.

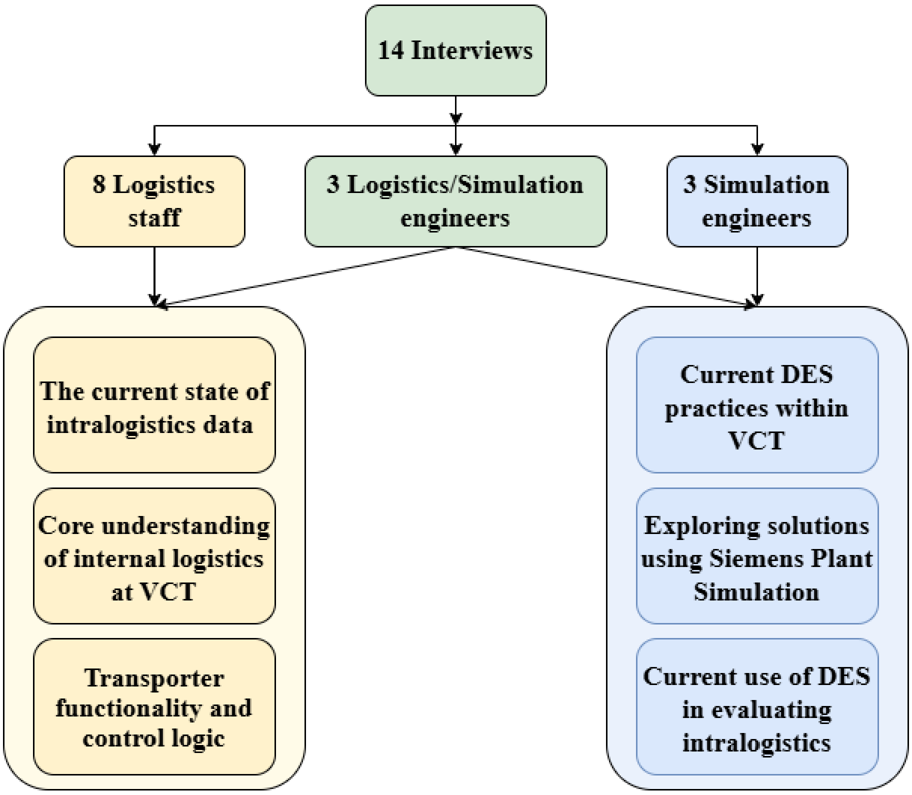

Figure 4.1: Findings from interviews

4.2.1 Current state for internal logistics

The logistics flow is driven by two interactive systems, MAS (Manufacturing Automation System) and VCLAS (Volvo Common Logistics and Sequencing system).

These systems control the material handling for both manual trucks and AGVs. The first step in a logistics operation occurs in the MAS, where a transport order is generated. This order contains information related to material movement, such as article numbers, storage locations, and serial numbers used for package changes.

Today, internal logistics calculations and analyses are performed using local, purpose-specific Excel files, typically adding a general 9% buffer to process times to compensate for losses and variations that cannot be predicted in advance. These files are often developed for individual use cases and are not standardized across factories.

An issue identified during the interviews was the lack of documented behavior and control logic for the current transporters at the production facility. The necessary knowledge exists as tacit knowledge among senior logistics staff at VCT and was not documented or accessible in shared systems. Furthermore, the practicality of traffic rules and interactions exists as only tacit knowledge held by experienced personnel, rather than being formally documented. As a result, logistics planning often relies on supplier-provided data, which may not fully reflect actual operating conditions within the factory.

From the interviews, interviewees expressed a need for more generic, standardized behavior models to better visualize traffic flows and identify bottlenecks. Understanding how different transporters interact in shared spaces was described as challenging, particularly regarding traffic congestion and capacity constraints.

4.2.2 Current work with DES

Based on the qualitative study, a state-of-the-art review of the intralogistic transporter and digitalization was conducted to understand how they operate at VCT. Today, DES is primarily used at VCT to analyze manufacturing flows for concept and is commonly applied during the validation and verification of new production lines (greenfield projects) and to optimize existing systems (brownfield projects). All simulations are currently built manually, based on customer requested assignments within VCT. It was not common at VCT today to use DES to evaluate internal logistics flow with transporters.

As a result, data is often supplied in a shared, disposable Excel sheet and is systematically not stored externally or verified by the simulation engineer. From the interview with the simulation engineer, it became clear that the process for collecting missing data and where to find it, is difficult. A challenge from the interviews is the current state of data management. The information needed for simulations is spread across many data sources, and logistics and production departments use separate data management systems that have different access levels. This results in a difficult overview of what data exists, where it is stored, and what data is up to date. The fragmented structure makes it hard to access information and is time-consuming to find.

Simulation Engineers also noted that certain behaviors often need to be “faked” in the simulation model, for example, by using stations with time delays rather than fully modeling complex transporter movements as they are in reality. The reason is to keep the models simple, and the transporter is not of interest for the project or because certain behaviors can't be accurately simulated in the software.

The interviews with the simulation engineers provided important insights into the construction of simulation models in TPS. One key insight was to follow the KISS principle ("Keep It Simple, Stupid") [57], emphasizing that a simpler model is more reliable, easier to validate, and easier to communicate across departments. According to the simulation engineer, only the parameters that influence system behavior should be included. This resulted in the identification of critical data, such as behavioral parameters and control logic.

4.3 Expectation identified from stakeholder interviews

The interviews revealed that the two main stakeholder groups, the production department (simulation engineers) and the logistics department, had different expectations for this study. The simulation engineers primarily aimed to reduce manual work by connecting the simulation tool to a database for transporters. This would enable the automatic generation of simulation models, something that has been discussed as a need among engineers for several years.

In contrast, the logistics department wanted to focus on overcoming the limitations of existing Excel-based calculations. Their goal was to enable more realistic and dynamic analyses of internal logistics systems. Overall, both departments share the goal to improve efficiency and consistency at VCC.

Although the departments have different expectations, they are centered around the need for structured, transparent, and accessible data. Another important insight from the interviews is the simplicity in both the simulation model and its data, enabling stakeholders with varying levels of expertise to understand and use the model. It also became clear that both departments want to move away from the current way of working, in which simulations are primarily based on single-flow analyses and input data are provided on a case-by-case basis.

To visualize and structure the identified expectations, an Expectation-matrix was developed (Table 4.1). All interviews were anonymized, and the respondents' expectations are summarized in the matrix. The matrix provided an overall framework for developing the simulation model, with the most important requirement being to balance functionality with simplicity. Emphasized the importance of developing a solution that supports generic and automated simulation while being easy to use. The expectations identified form the basis for the design and development of this thesis solution

Table 4.1: Expectation themes identified from stakeholder interviews

Expectation Themes	Reason	Source
Visualization of traffic flows and traffic bottlenecks	Enables understanding of vehicle interactions and congestion within the factory that Excel-based analyses cannot capture.	R6, R11, R14
Quantification of traffic disturbances	Allows evaluation of how mixed traffic (AGVs and manual trucks) affects throughput, delays, and performance in constrained areas.	R2, R9, R12
Fast feedback on layout changes	Supports fast feedback of layout or routing modifications and their impact on lead time and flow efficiency.	R6, R11
Validation of transporter configurations	Provides decision support to determine transporter requirements, rather than relying on supplier estimates.	R9, R11
Standardized and updated input data	Working towards a centralized and consistent data source for transporters in an intralogistic setting.	R7, R9, R12
Enable automatic model generation	Reduces manual effort and errors by enabling automatic creation of simulation components.	R6, R9, R11
Providing a generic behavior model	Provides reusable and standardized transporter logic, improving consistency and reducing rework across models.	R7, R11
Connection to external fleet managers	Enables testing of real control systems in a virtual environment before implementation.	R5, R6, R10, R12
Reduced person dependency	Improves robustness and reproducibility by using standardized templates and structured data instead of personal networks.	R7, R14

4.4 Generic transporter model

The interviews revealed that transporter behavior are primarily defined by how they execute transport tasks, rather than by their physical characteristics. In this

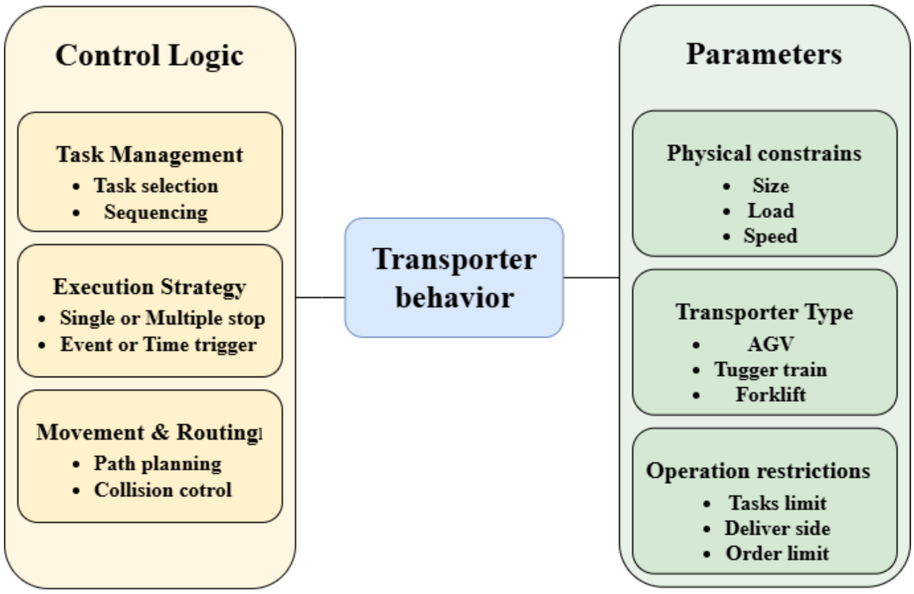

Figure 4.2: Conceptual model of transporter behavior

context, control logic emerged as the central aspect of capturing how transporters behave by documenting how transporters receive, prioritize, and carry out tasks.

The interviews also revealed that different types of transporters are used for specific operational purposes. To enable comparison and modeling of transporters, they were categorized based on behavioral characteristics, including how they are controlled, how they interact with their surroundings, and the roles they play in the transport process. Then, the transporter was categorized based on functional behavior, rather than physical properties.

This distinction is based on the fact that physical attributes such as size, load capacity, and speed are easily modified in the simulation environment through simple parameter changes. In contrast, behavior follows a different logic and plays a more fundamental role in defining how the system functions, making it hard to emulate in a simulation environment.

Based on these interview insights, three main behavioral categories of transporters were identified: AGVs, forklifts, and tugger trains. These categories reflect the key differences in how transport tasks are executed and controlled in practice. A more detailed description of these categories is provided in the appendix B, C, and D.

A conceptual model was developed to represent the transporter as a system. The model is structured around two main dimensions, behavior and parameters. An initial concept map was created early in the interviews to establish a shared understanding of transporter functions, elements, and constraints. This representation was then iteratively refined throughout the interview phase, resulting in the final conceptual model shown in Figure 4.2.

The behavioral part of a transporter captures the control logic and includes aspects such as task management, execution strategy, and routing. These elements define how the transporter operates and interacts with tasks.

The parameter dimension comprises transporter physical parameters, operational parameters, and type-specific parameters. Together, these describe the physical and operational conditions under which the transporter operates.

A key finding from this work is that separating behavior and parameters provides a structured way to represent transporters in a simulation environment. It's important to highlight control logic as the primary factor influencing system performance.

4.4.1 Generic simulation model Structure

To ensure a standardized and reusable structure for modeling in DES, a generic model structure was developed. This structure was formulated using a hybrid approach based on the DELS system proposed by Sprock and Bock [24], complemented by expert input from the project supervisor at VVC. DELS was selected because it provides a structured way to organize logistics systems into well defined system elements, enabling a clear separation among products, resources, processes, and control logic. This makes it suitable for developing a generic model that supports consistency, comparability, and reuse across different simulation implementations. The purpose of this approach was to define the necessary simulation building blocks required to accurately represent intralogistics processes and transporter behavior within the system.

The generic model is constructed as a set of modular simulation building blocks derived from DELS [24]. The model's intent is to identify which system responsibilities must be present in an intralogistics simulation and to explicitly assign them to well-defined components. The model structure is organized such that each DELS element is implemented through one or more simulation building blocks, depending on how system responsibilities are allocated.

The required simulation building blocks for intralogistics were derived from qualitative research and supervisory input. Figure 4.3 illustrates the relationship between the defined simulation building blocks and the corresponding DELS elements. The block structure was established by mapping each simulation building block to its relevant DELS system element. These relationships describe functional responsibility, indicating which component owns information, executes logic, or performs actions for a specific DELS element. The relationships are conceptual and structural in nature and do not represent runtime material or information flow.

As shown in 4.3, the generic model structure comprises a set of simulation building blocks, each responsible for a specific part of the intralogistics system.

The Material Station represents products and parts and is the sole owner of all product-related information, including inventory levels, part balances, and consumption parameters. It controls local flow decisions, such as storage assignment

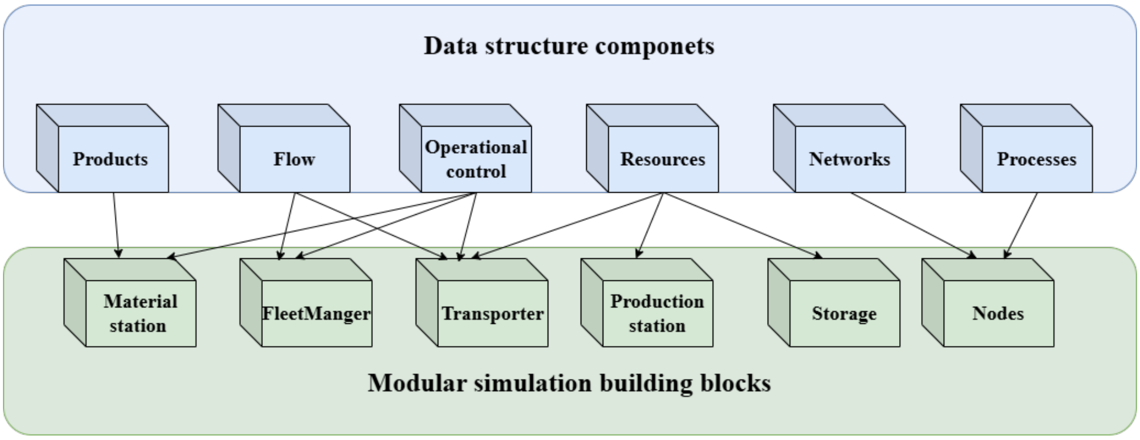

Figure 4.3: Generic simulation model structure

and empty container destinations, and generates logistics orders based on material demand.

The Fleet Manager oversees operational control of transport execution. Based on orders generated by the Material Station, it assigns and coordinates transport tasks without owning any product or material information.

Transporters are modeled as resources that move materials between Material Stations and Storage locations. They perform assigned transport tasks and do not own products or make independent control decisions.

The Production Station functions as a consumer of material and generates demand by consuming products from the Material Station. Product ownership and inventory management remain centralized at the Material Station.

Storage represents a passive element within the logistics flow where products may temporarily reside. It does not own product information and performs no control logic beyond serving as a buffer.

Finally, Nodes define the logistics network by specifying how locations and routes are connected. Nodes also represent local process functionality, such as loading, unloading, waiting, and crossing, as well as location-specific operational constraints.

4.5 Results of Simulation Model for exploration/design

This Section presents the results from the modeling exploration conducted in this thesis. The section focuses on developing the DES model in TPS and implementing transporter behavior and control logic in an intralogistics environment. It describes the structure of the developed model, the handling of transport orders and tasks, and the methods for representing different transporter behaviors. In addition, the section presents the prototype developed to generate simulation model structures from standardized external input data.

4.5.1 Modeling transporter behavoir

Modeling transporter behavior in a DES environment is complex because it involves multiple interacting elements and parameters. These include, for example, routing strategies, movement characteristics, resource availability, and interactions with other system components. Attempting to model all these aspects in detail is not feasible in the short time this thesis is written.

To manage this complexity, this work focuses on the primary differentiating factor among the transporters identified in the qualitative study systems the control logic. The control logic defines how transporters interpret and execute transport orders, and thereby directly influences system performance and behavior. Rather than emphasizing detailed physical movements or parameters, the model focuses on how orders are made and executed in transport operations.

In this context, a transport order is defined as a sequence of tasks, typically consisting of four main steps: pickup of a loaded unit, delivery of the loaded unit, pickup of an empty unit, and delivery of the empty unit. These steps are conceptually treated as subtasks within a complete order.

The control logic implemented in the model is event-driven, meaning that transporter actions are triggered by changes in the system state, such as material availability, processing completion, or arrival at a location. This approach allows the model to dynamically respond to system conditions and ensures that transporters operate in accordance with the system's current state.

To enable the development, verification, and comparison of different control logic solutions, a dedicated test environment was created. This environment represents a simplified intralogistics system based on the qualitative results, including material stations, production stations, storage locations, and a connecting road network. Within this controlled setting, the key components required for evaluating transporter behavior were implemented: transporters, an order/fleet management system, and the associated control logic.

The primary purpose of this test model is twofold. First, it verifies the correctness of the implemented control logic, ensuring that transport orders are executed as intended. Second, it provides a consistent platform for comparing different control strategies and evaluating their impact on system behavior. By isolating the control logic within a simplified but representative environment, the analysis can focus on the core mechanisms that differentiate transporter performance.

4.5.2 Structure of the DES model

The developed DES model is implemented within an SPS model file and organized using a structured Class Library. As shown in Figure 4.4, all created model frames are located within the folder "Models". The naming convention used in the model distinguishes between standard library objects and user-defined components, where an underscore prefix "_" indicates that the object is specific to this model.

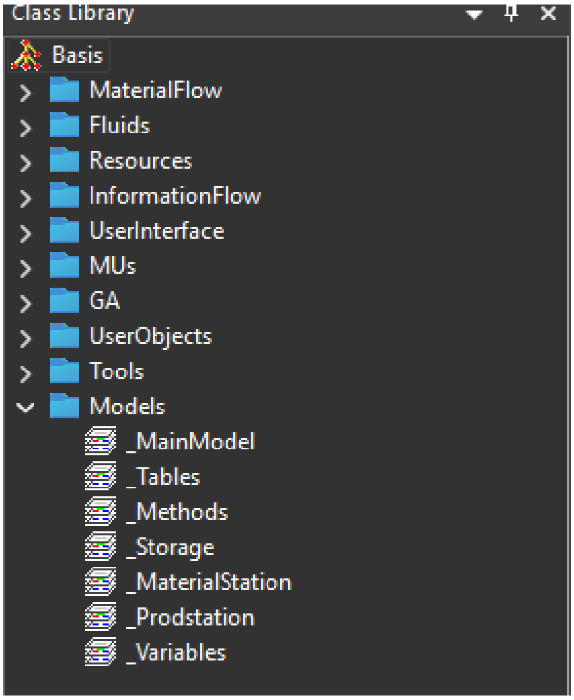

Figure 4.4: Class Library

A consistent naming structure is also applied across different simulation objects to clearly identify their type and function. Methods are prefixed with "m_", tables with "t_", and variables with "v_". This systematic naming convention improves readability and makes it easier to understand, maintain, and extend the model by clearly indicating each object's role.

The model is built using a modular structure, in which each component is defined as a separate frame that acts as a generic building block. These building blocks represent different parts of an intralogistics system and can be reused and combined in different ways to create alternative system layouts and structures. This approach makes the model flexible and easier to modify, as individual components can be developed and adjusted independently of the overall system

The frame "_MainModel" is the main environment where the simulation is executed, as shown in Figure 4.5. It contains the layout of the intralogistics test system, including transport networks, stations, and material flows. The layout is abstract and includes only the elements needed to test transporter behavior and order execution.

Within the "_MainModel" frame, the transport network is defined by markers (e.g., "Marker1-13"), which serve as nodes that connect material, storage, and production stations. These markers form the routing structure that enables transporter movement. Three parallel tracks, "Track1-3," are included mainly to prevent blocking

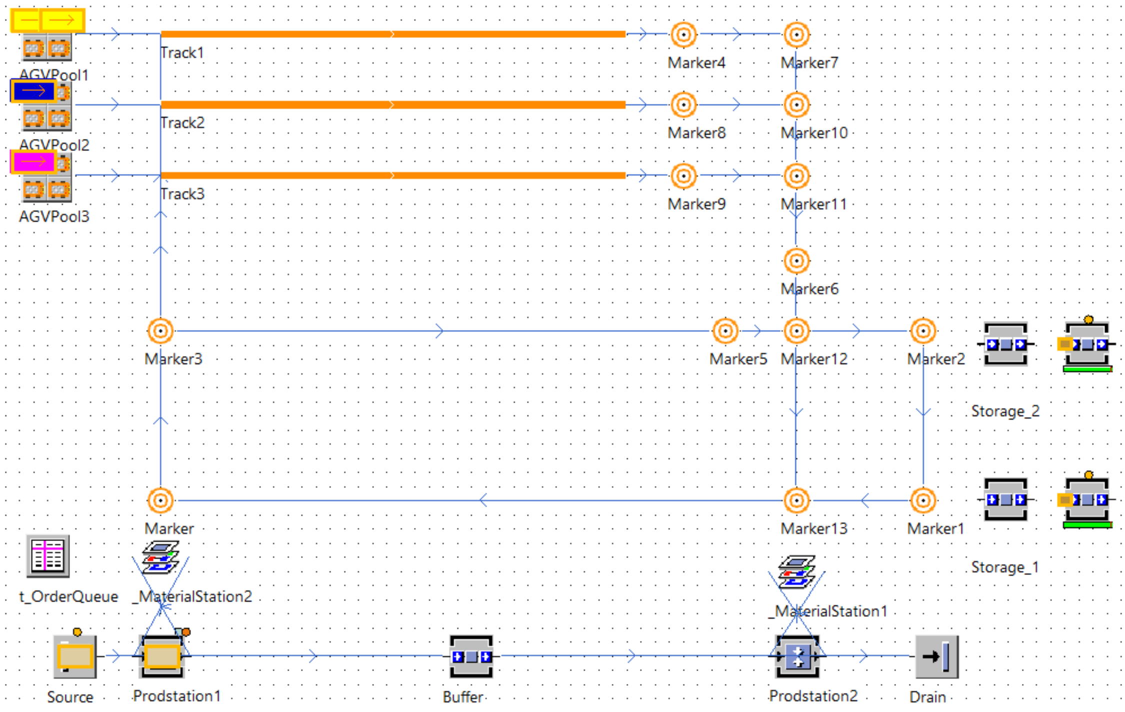

Figure 4.5: Main model frame

issues in the distance control method when leaving the AGVpools; they therefore serve primarily as parking positions for idle transporters.

Transporters are introduced into the system via AGVpools. The transporters are visually differentiated using color coding: yellow represents AGVs, dark blue represents tugger trains, and pink represents forklifts. This supports the analysis of transporter behavior during simulation.

The production stations are included only to generate the events that control the logistics and transporter flow. They consume parts from the material stations, triggering transport orders within the system, while no detailed production logic is modeled. The material stations themselves contain the logic for creating transport orders and for managing a significant part of the flow in the model, as described in more detail in Section 4.5.3. Storage is implemented as a simplified component where containers are always available for pickup, with no stock balance or inventory dynamics. It functions as a point in the transport network for collecting loaded containers and delivering empty ones. These simplifications follow the overall modeling approach, which focuses on transporter control logic rather than on detailed production or storage behavior.

The methods used in the model are mainly stored in the "_Methods" frame, where the control logic is implemented. The only exceptions are the "Init" and "Reset" methods, which are located in the "_MainModel" frame to ensure correct model execution. The "_Tables" frame contains the data structures used in the model, including representations of tasks, transporter parameters, and lists of available transporters, while the "_Variables" frame provides global parameters used throughout the model.

This modular structure allows the main model to reference and integrate predefined components while maintaining a clear separation between system layout, logic, and data. The structure is inspired by results in the automated model generation literature, in which DES models are organized as reusable building blocks to improve flexibility and scalability. The following subsections provide a more detailed description of each of these components.

4.5.3 Material Station frame

The Material Station is the central component of the intralogistic model, managing material flow and generating transport orders. It contains the main logic for handling part consumption, inventory balance, and order creation. The station also defines its location in the transport network via a connection variable that specifies the node it is connected to, as shown in Figure 4.6.

A key aspect of the model is that transporter behavior is triggered by orders, which are constructed as sequences of predefined tasks. Each order follows the same structure consisting of four tasks: pickup of a loaded unit, delivery of the loaded unit, pickup of an empty unit, and delivery of the empty unit, as defined in Table 4.2. This task-based structure is the primary mechanism for controlling transporter operation in the system.

Table 4.2: Task table with full order

Destination	Location	PartName	Task	TaskType	Phase	OrderID
`Marker2`	`Storage_2`	B	PickupFull	1	1	2
`Marker1`	`MaterialStation_2`	B	DeliverFull	2	2	2
`Marker1`	`MaterialStation_2`	B	PickupEmpty	1	2	2
`Marker2`	`Storage_2`	B	DeliverEmpty	2	3	2

Based on information in "t_BOM" and "t_consumption", parts are created and placed in buffer objects, from which they enter the assembly station. This process serves as the fundamental event trigger that initiates the intralogistics flow. The assembly station consumes parts according to the product variant being processed, as defined in the "t_consumption" data. As products are processed, the parts balance is continuously updated, and when it reaches a defined order level, a transport order is generated to replenish the material. In this way, the Material Station controls both the flow of parts and the triggering of transport operations, with a detailed description of its objects and their functions provided in Appendix F.

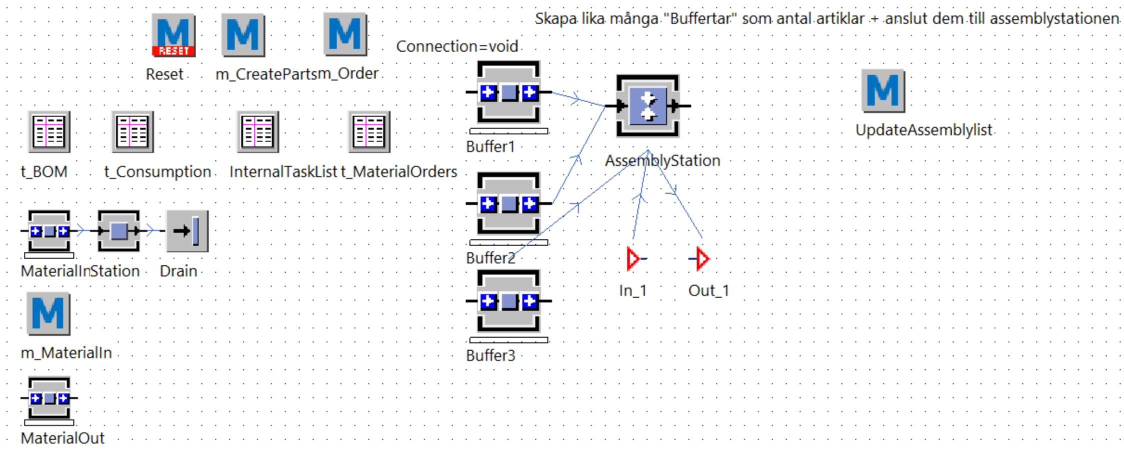

Figure 4.6: Material station frame

4.5.4 Tables frame

The tables in the model store the data structures required to support transport order execution and control logic. While the methods define how decisions are made, the tables provide the information used in those decisions, including transporter parameters, task structures, and available resources. The tables are organized into groups corresponding to different transporter types and control logic implementations Figure 4.7, with detailed descriptions of their functions and contents in Appendix F.

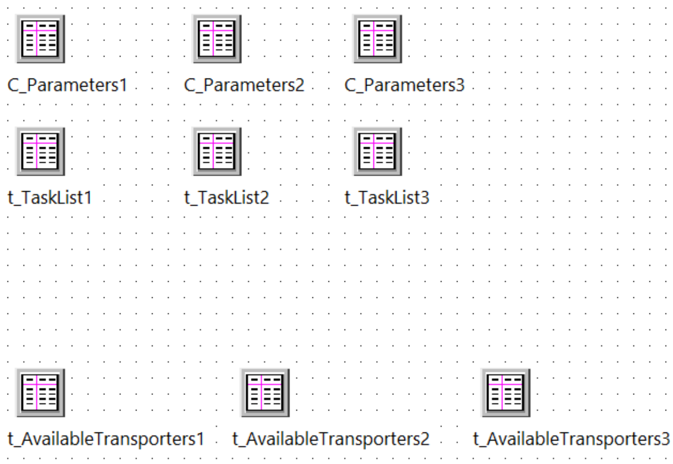

Figure 4.7: Tables Frame

It should be noted that data used in the full model, such as the Bill of Materials "t_BOM", consumption data "t_Consumption", and transporter parameters "C_Parameter" tables, could be externally defined and stored in a database. Structuring the data in this way supports a more generic modeling approach, improving reusability and enabling easier comparison between different models and DES applications.

4.5.5 Methods frame

The methods in the model contain the logic that governs how transport operations are executed. The main control logic related to transport orders is implemented in the "_Methods" frame, as shown in Figure 4.8, while the specific functions of these methods are described in Appendix F. This control logic assigns transporters and ensures that the predefined tasks for each order are executed in the correct sequence and by the appropriate transporter type.

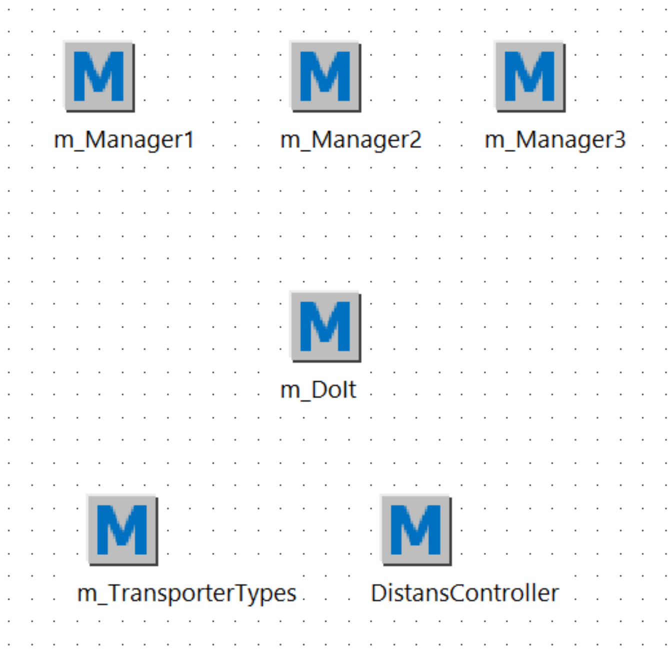

Figure 4.8: Methods Frame

The core order and behavior control is implemented in the methods "m_Manager1-3", and "m_Dot". These methods handle task assignment and control how transporters execute their orders. As shown in Table 4.3 and Table 4.4, the manager methods organize tasks from multiple orders to control how transporters execute their work. Before sorting, each order follows the predefined task structure. After sorting, the tasks are reordered by transport type, allowing the transporter to execute them in transporter-specific order. In this way, transporter behavior is modeled by controlling the sequence and organization of tasks rather than modifying the individual tasks themselves based on the transporter.

Table 4.3: Tugger task table before sorting

Destination	Location	PartName	Task	TaskType	Phase	OrderID
Marker2	Storage_2	A	PickupFull	1	1	1
Marker1	MaterialStation_2	A	DeliverFull	2	2	1
Marker1	MaterialStation_2	A	PickupEmpty	1	2	1
Marker2	Storage_2	A	DeliverEmpty	2	3	1
Marker2	Storage_2	B	PickupFull	1	1	2
Marker1	MaterialStation_2	B	DeliverFull	2	2	2
Marker1	MaterialStation_2	B	PickupEmpty	1	2	2
Marker2	Storage_2	B	DeliverEmpty	2	3	2

Table 4.4: Tugger task table after sorting

Destination	Location	PartName	Task	TaskType	Phase	OrderID
Marker2	Storage_2	A	PickupFull	1	1	1
Marker2	Storage_2	B	PickupFull	1	1	2
Marker1	MaterialStation_2	A	DeliverFull	2	2	1
Marker1	MaterialStation_2	A	PickupEmpty	1	2	1
Marker1	MaterialStation_2	B	DeliverFull	2	2	2
Marker1	MaterialStation_2	B	PickupEmpty	1	2	2
Marker2	Storage_2	A	DeliverEmpty	2	3	1
Marker2	Storage_2	B	DeliverEmpty	2	3	2

The combination of the manager methods "m_Manager1–3" and "m_Dot" and the "tasklist", both in the central tables and within each transporter, represents a modular control approach that could be externalized. In this structure, the task lists serve as the interface between order generation and execution, enabling the control logic to be moved to an external fleet management system and database.

4.5.6 Automated marker layout

To evaluate the feasibility of automatically generating intralogistics simulation solutions based on standardized input data, a prototype was developed in TPS. The prototype investigated whether a standardized external data source could be used to generate a consistent and reusable marker-based layout. The data source was structured in an external Excel file and was selected as it is widely used in VCC, particularly within logistics departments. The selected input parameters were based on the identified requirements for the generic model structure and the VCC supervisor input.

The information required to generate the layout structure included several parameters. The parameter “Marker_name” provides each marker with a unique identifier, which enables it to be referenced throughout the model. The “Position” parameter defines the marker’s coordinates within the simulation layout. To establish the transport paths, the “Connection” parameter specifies how markers are linked to one another and defines the routes. Finally, the “Function” parameter defines the role of each marker, such as a source, loading or unloading point, or intersection. This determines how transporters interact with the marker during simulation. Visualization of the external Excel document can be seen in Figure 4.10 and 4.11.

When the input data is defined, the external data source is read into the model using dedicated methods and stored in table structures within TPS. These tables serve as an intermediate layer between the input data and the simulation model, allowing the information to be accessed consistently and updated when the external source changes. The table data is then interpreted by the model, which automatically generates the marker layout and connections. Figure 4.9 shows the TPS setup.

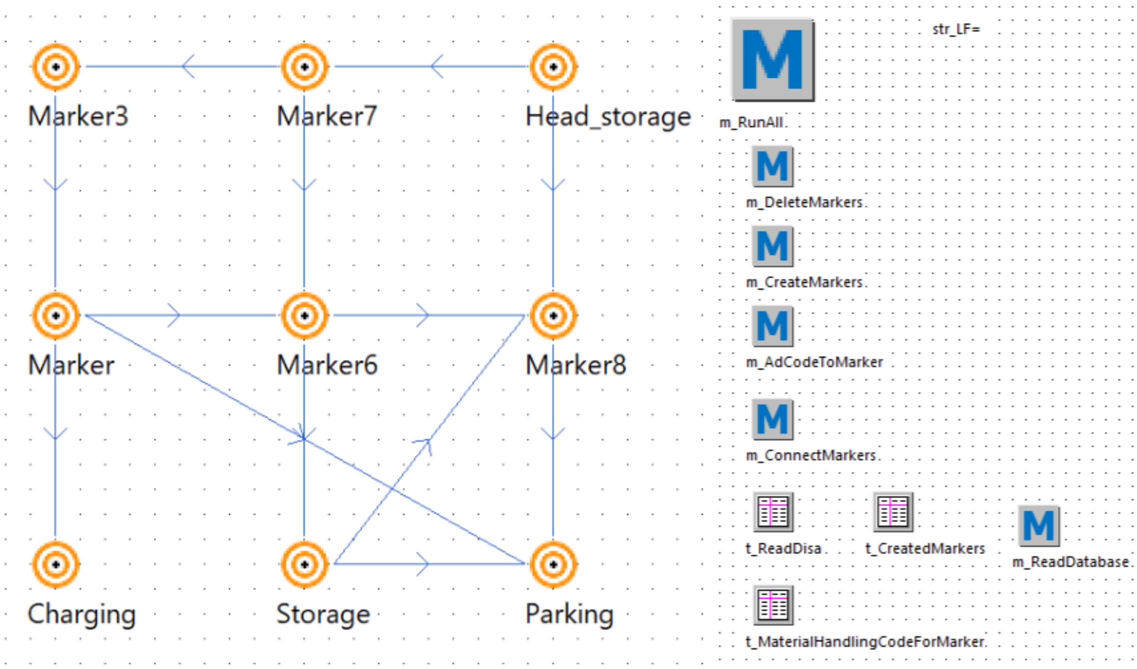

Figure 4.9: Markers generated from external data & methods

By using tables in this way, the model separates data from implementation. Instead of manually creating simulation objects, the methods read and process the table data. This structure enables translation from external input data into simulation objects. This makes it possible to modify the simulation model by updating the input data. A more detailed description of the methods and table functionality is provided in Appendix G.

Name	Function	X	Y
Charging	m_charige	100	300
Storage	m_storage	200	300
Parking	m_parking	300	300
Marker		100	200
Marker6		200	200
Marker8		300	200
Marker3		100	100
Marker7		200	100
Head_storage	m_storage	300	100

Figure 4.10: Information from external database

Fromobject	Toobject
Storage	Parking
Marker	Marker6
Marker6	Marker8
Marker3	Marker
Marker	Charging
Marker6	Storage
Marker7	Marker6
Marker8	Parking
Head_storage	Marker8
Head_storage	Marker7
Marker7	Marker3
Marker	Parking
Storage	Marker8

Figure 4.11: Information from external database

5

Discussion

This chapter discusses the thesis's findings by analyzing the results in relation to the research questions. The research contributions are then highlighted, followed by a discussion of the study's limitations and suggestions for future work. Finally, the chapter considers the ethical, societal, and ecological implications of the research.

5.1 Answers to Research Question 1

RQ1: How can a standardized database for intralogistics and transporter behavior modeling in discrete event simulation enable consistent and comparable evaluation of different intralogistics transporter solutions?

The results of this study indicate that standardized input data are necessary to create consistent and comparable DES models in intralogistics systems. RQ1 is answered by demonstrating how a structured, standardized data foundation enables the systematic evaluation of different transporter solutions.

Results from the literature review also support this finding, as section 4.1.1 identifies automated model generation as an important factor for achieving consistency and comparability in DES. From the literature findings in Section 4.1, three important elements for achieving comparability in intralogistics DES were identified. First, data should be collected and organized in a standardized format within an external source. Second, the simulation model should have a generic structure in which system configurations can be changed via input data rather than by redesigning the model. Third, standardized data enable automatic or semi-automatic model generation, which supports more consistent model implementation and greater comparability across applications.

However, the literature also highlights that such automation depends on structured, standardized input data, an area in which VCT currently faces challenges. It was observed in the interview (Section 4.2.2) that simulation models were manually built using case-specific Excel files and fragmented data sources. This limits model reuse and makes comparison between simulation studies difficult, since differences in results may come from modeling assumptions rather than actual system differences.

Consequently, these findings show that comparability is primarily achieved through consistent model generation using standardized data, rather than through advanced simulation logic alone. By using a standardized database as input to a DES environment, simulation models can be generated automatically rather than manually created for each case. This reduces modeling effort and decreases the influence of individual modeling assumptions and practices. As a result, differences in simulation results can be evaluated in transporter configurations rather than to inconsistencies in model implementation.

This concept was further explored through a simplified layout generation prototype in Section 4.5.6, which used standardized input data to generate a transport network within the simulation environment. The results demonstrate that it is practically possible to generate consistent simulation structures from standardized data. However, the prototype has a limited scope and does not include the full complexity of transporter behavior or intralogistics systems. Therefore, while the study shows that standardized data can support consistent model generation, it should be seen as an initial step toward a more comprehensive framework.

5.2 Answers to Research Question 2

RQ2: How can facility specific transporters and intralogistic systems and real-time dispatching be implemented in discrete event simulation to represent real-world transporter behavior?

The results of this study show that intralogistics transporter behavior in DES can be modeled in part using task-based control logic rather than detailed physical representations. This directly addresses RQ2 by demonstrating how transporter behavior can be structured and implemented consistently and in a reusable way.

Results from the interviews in Section 4.2 show that transporter behavior in industrial practice is primarily determined by how transport orders are assigned, prioritized, and executed. Although the physical layout and intralogistic infrastructure influence the system, they do not fully determine its behavior. Instead, behavioral differences were primarily driven by operational logic, such as dispatching strategies, the sequencing of transport tasks, and order handling. This highlights the importance of explicitly modeling control logic in addition to system structure.

This perspective was further developed in the conceptual model in Section 4.4, where transporter operations were organized into a generic behavioral model. In the simulation implementation in Section 4.5.1, some of these concepts were implemented by dividing transport jobs into sequences of atomic tasks. This structure allows transport orders to be defined independently of their execution, enabling behavior to be controlled by logic rather than non-modular model components.

By separating order definition from execution, the model can represent different transporter types and behaviors by changing the control logic without modifying the model structure. This allows the same simulation framework to be reused across multiple simulation tools, where behavioral differences are introduced through control rules and parameter settings. As a result, behavior modeling becomes more scalable and adaptable compared to case-specific implementations.

This resulted in a simulation model in Section 4.5.1 that demonstrates the feasibility of this approach, as transporters were able to adopt different behavior using the implemented task structure and control logic. The results show that correct execution of transport sequences can be achieved without detailed physical modeling, and that the main aspects of transporter behavior can be represented through task execution in DES.

However, the behavioral representation in DES remains simplified and does not capture the full complexity of real-world decision-making, including dynamic prioritization and order reassignment between multiple transporters. In addition, the model does not aim to provide a fully functional intralogistics solution in DES, but rather to validate the feasibility of the conceptual approach. Therefore, further research is needed to extend the framework toward more advanced behavioral modeling and performance evaluation.

5.3 Contribution to Practice

This thesis contributes to practice by demonstrating how intralogistics systems can be analyzed using a structured, dynamic DES approach rather than relying on static, case-specific calculations. As identified in the interviews Section 4.1, current practices at VCT rely heavily on Excel analyses and manually constructed DES models, which limit the ability to capture interactions among transporters.

The proposed approach enables visualization of logistics flows and transporter interactions, allowing identification of traffic disturbances, congestion, and behavioral effects that are difficult to capture using current methods. The results from the interview in Section 4.2 show that it is challenging to foresee transporter interactions in shared spaces. By simulating these interactions, it improves understanding of system constraints and supports decision-making in intralogistics evaluation.

In addition, standardized data combined with a generic simulation model enables more efficient model development. As observed in Section 4.2.2, simulation modeling at VCC is currently a time-consuming, manual process with little to no reusability for the DES model. By separating data from the DES model logic, the approach enables greater reusability and faster evaluation of the overall DES project. Standardized behavioral models also improve consistency across simulation studies. By using the same data structures and control logic, the approach reduces variability between models and enables more reliable comparison of simulation results.

5.4 Contribution to Theory

This thesis has contributed to showing research on data standardization and automated model generation in DES in the scope of intralogistics systems. While prior research primarily focuses on production process simulation [29, 13], this thesis demonstrates how similar approaches can be adapted to intralogistic systems and to transporter behavior within them.

A contribution of this thesis is the separation of transporter behavior from system structure and physical parameters, which aligns with structured modeling approaches such as DELS [25]. This thesis applies DELS structured, component-based approach to intralogistics and transporter behavior. This highlights operational control as a separate and central part of the system, rather than something that is built into simulation objects.

When transport operations are modeled as task sequences, behavior can be defined independently of the simulation model. This is in line with research on input data management and structured simulation data, which highlights the benefits of keeping system logic and data separate to improve reusability and consistency [19, 21]. By defining behavior as data that is stored outside the model, a clearer separation is created between the system and the data. This helps address known challenges related to reusing and comparing simulation data [20].

The study is related to research on automated model generation in DES, where separating simulation logic from system-specific data is a central principle [29]. Previous studies have focused on how structured, standardized input data can support the development of reusable, automated simulation models for production processes. This thesis instead demonstrates how these automation principles can be applied to intralogistics systems, with a particular focus on transporter behavior. Rather than introducing a new automation methodology, the study shows how existing data-driven approaches can be extended beyond production systems and adapted to intralogistics contexts.

This thesis presents an approach that provides a more modular and general representation of intralogistics and transporter behavior systems, grounded in DES theory [13] and supported by principles of standardization and structured data representation [22, 25]. To conclude, this thesis contributes to theory by demonstrating how transporter behavior can be formalized, separated, and reused within a standardized simulation context, and strengthening the link between intralogistics modeling, data standardization, and automated simulation methodologies.

5.5 Limitations and Future Work

This study has several limitations related to data availability, modeling scope, and implementation in DES, which also point to areas for future work. A key limitation concerns data availability and knowledge management. As identified in the interview study Section 4.2, information about transporter behavior and intralogistics is fragmented across systems and often exists as tacit knowledge held by experienced personnel. This limited the completeness and consistency of the data used. Future work should focus on developing more structured, centralized data management approaches for intralogistics to support clearer, more accessible data.

The behavioral representation of the transporter in this study is simplified. The model mainly focuses on order execution and task-based control logic, while important aspects such as traffic dynamics, routing decisions, charging strategies, and human operator variability were not explored. These factors are important in real-world intralogistics systems and warrant further exploration to improve the accuracy of future DES models.

In addition, the findings on automated model generation are limited. While the study shows that standardized data can be used to generate simulation structures, automation was only applied to marker layout. Transporter behavior and control logic were implemented separately in another model with a generic structure, enabling future automated generation. Future work should explore this further and how behavioral rules can be defined in standardized data formats to enable greater automation for DES.

Many limitations are also related to the simulation tool, Siemens Plant Simulation. Performance constraints and limitations in transporter movement affected the model's realism, necessitating simplifications during implementation. Future work may explore alternative modeling approaches or different DES tools to improve scalability and accuracy.

Lastly, this study represents a small proof-of-concept implementation and has not been tested in large-scale industrial systems or with real operational data. Future work should focus on validating the approach in practical settings and developing more refined solutions to support broader industrial use.

5.6 Ethical, Societal, and Ecological Implications of the Research

This research is analyzed from ethical, societal, and ecological perspectives in relation to the United Nations Sustainable Development Goals [58]. The developed approach primarily aligns with Goals 9 (Industry, innovation and infrastructure), 12 (Responsible consumption and production), and 13 (Climate action), while also raising important considerations.

DES enables evaluation of system configurations in a virtual environment, reducing resource-intensive trial-and-error and lowering material waste and energy use. From an ecological perspective, this thesis supports more sustainable intralogistics by improving efficiency. Improved routing and reduced congestion also contribute to lower environmental impact, supporting goals 12 and 13.

From a societal perspective, the research promotes more transparent and data-driven decision-making. By reducing reliance on tacit knowledge and fragmented data, the approach supports more consistent planning, improved collaboration, and more stable operations, supporting goal 9.

From an ethical perspective, simulation models are simplified representations and should be used carefully, as incorrect assumptions may lead to misleading results. In addition, increased efficiency and automation may affect the need for the workforce. Optimized systems can reduce the need for certain roles, potentially leading to changes in job structures or job losses. This highlights the importance of transparent, validated, and responsible use of simulation in practice.

6 Conclusion

To conclude this thesis, the behavior of intralogistics transporters was investigated and modeled in DES to evaluate the consistency and comparability of different transporter solutions. The results demonstrate that using a standardized data structure is essential for automating layout generation and that external input data can be translated into simulation models, thereby providing consistent and comparable DES models. Furthermore, the study shows that transporter behavior can be effectively modeled in DES using a task control logic approach.

A key finding is by organizing transporter behavior data in a structured, external format, behavioral differences can then be introduced through control logic rather than by modifying the simulation model. This approach supports the development of generic, reusable simulation models by enabling automation. This reduces manual modeling effort and enables more consistent and reliable comparisons among alternative intralogistics transporter solutions.

This thesis's implementation in the DES model is limited and simplified in several aspects compared to real-world systems. This calls for further research on data-driven and behavioral structures for simulation models. Future work should focus on increasing behavioral detail, improving data automation, and validating the approach in large-scale industrial settings.

In conclusion, this thesis contributes toward bridging the gap between standardized data management, behavioral logistics modeling, and automated DES generation, demonstrating how these areas can be integrated to support the next generation of autonomous, scalable, and data-driven evaluation of intralogistics simulation environments.

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A

Base questions for interview

Intervjuguide

1. Introduktion

Intervju med:

Datum:

- Förklara syftet med exjobbet.
- Fråga om det är okej att spela in intervjun för transkribering.
- Bekräfta att mötet är avsatt till cirka 60 minuter.

2. Roll & Arbetsområde

- Vad gör du på Volvo Cars?
- Vilka system jobbar du med?
- Vilka materialhanteringssystem använder ni? (MAS/MAST)

3. System & Datahantering

- Vilka fleet manager-system finns och används samma i alla fabriker?
- Lagrar ni information om transportörer? Vilken sorts information och var lagras den?
- Vilken information saknas? Var hittar vi dessa värden?

4. Transportörernas Användning

- När behövs transportören?

- Varför valde ni transportören?
- Var används transportören?
- Hur och i vilka situationer används transportören?
- Vilka transporter har ni i anläggningen?
- Är deras beteende standardiserat eller anpassat efter området?

5. Beslutsfattande & Prioriteringar

- Vad värdesätter ni när ni väljer en transportör?
- Vem bestämmer vilka transportörer som ska användas?
- Hur väger ni alternativen mot varandra?
- Vilka var de viktigaste avvägningarna?
- Vilka KPI:er är viktigast i praktiken?

6. Informationsbehov & Förväntningar

- Vad hade ni velat få ut av vårt arbete?
- Vilken information om transportörer upplever ni saknas?
- Vilken information hade underlättat ert arbete om den fanns tillgänglig?

7. Övriga Nyckelpersoner

- Vilka personer tror du är av intresse för oss?

B

AGV Operations

This section provides a descriptive overview of Automated Guided Vehicle (AGV) operations at Volvo Car Torslanda. The description is based on interview data.

B.1 Application of AGVs

Table B.1: Application of AGVs

Aspect	**Description**
Primary function	Transport of rigid and large-scale materials, such as heavy steel racks, primarily in the A-shop.
Operational suitability	Well suited for heavy loads and less congested factory areas. Generally less flexible and time-efficient than manual operators.

B.2 Transport Order

Table B.2: Transport Order

Aspect	**Description**
Trigger mechanism	Production line signals when material is empty or running low trigger an AGV orded via a PLC signal.
Planning systems	Requests come from MASWEB and VCLAS for transport planning.
Order structure	Each request generates four orders: two assigned to AGVs (empty rack collection and full rack delivery) and two assigned to warehouse forklifts for loading on to AGV.

Table B.3: Fleet management and task assignment

Aspect	Description
Fleet manager	AGV movements are coordinated by a Fleet Manager. Volvo Cars is transitioning from BAM to Kinexon.
Task allocation	Tasks are assigned within predefined zones based on estimated completion time rather than proximity alone.

Table B.4: Navigation and traffic control characteristics

Aspect	Description
Routing	AGVs operate on fixed, pre-programmed routes and cannot reroute dynamically.
Navigation method	Positioning is based on laser reflector navigation using fixed reflectors in the roof.
Collision avoidance	Node-based reservation system prevents AGVs from occupying the same zone simultaneously for AGV.
Safety behavior	Safety scanners stop the AGV when obstacles enter the detection zone. overtaking AGVs is not permitted by other transporters.

B.3 Fleet Management and Task Assignment

B.4 Navigation, Traffic Control, and Safety

B.5 Battery Management

Table B.5: AGV battery

Aspect	Description
Charging	AGVs are sent to charge when battery levels reach approximately 20%.
Charging limit	Charging continues until battery levels reach around 80%.
Operating time	A full charge supports approximately 3-5 hours of operation.
Charging duration	A charging cycle takes approximately 2 hours.

B.6 Parking Rules and Task Prioritization

Table B.6: Parking behavior and mission handling

Aspect	**Description**
Idle behavior	AGVs without assigned tasks move to designated parking or charging locations.
Task prioritization	No task prioritization is implemented. Tasks are processed in the order they are orded.

C

Forklift Operations

This section provides a descriptive overview of Forklift operations at Volvo Cars Torslanda. The description is based on interview data.

C.0.1 Role and Operating

Table C.1: Role and application of forklifts at Volvo Cars

Aspect	**Description**
Vehicle type	Forklifts, also referred to as counterbalance trucks (*motviktstruckar*), operated by human drivers.
Operational flexibility	Human operation enables adaptive and flexible behavior that automated systems.

C.0.2 Usage Restrictions

Table C.2: Forklift usage restrictions and operational areas

Aspect	**Description**
Fork-free directive	Forklifts are generally restricted due to policy implemented for safety reasons.
Primary usage	Forklifts are mainly used in storage areas for loading and unloading trucks or containers.

C.0.3 Material Handling

Table C.3: Forklift operation and material handling

Aspect	Description
Trigger mechanism	Forklift operations are mainly ad hoc and visually driven rather than system-triggered.
Line guarding	In the A-shop, operators manually monitor production areas and replenish material when inventory levels are observed to decrease.
Transport pattern	Typically, forklifts transport a single unit, such as one pallet or rack, from storage areas to designated transfer points.

C.0.4 Human-Dependent Behavior

Table C.4: Human-driven forklift behavior

Aspect	Description
Behavioral variability	Forklift behavior is highly dependent on the individual operator, resulting in variability that is difficult to represent in simulation models.
Route adherence	Although predefined routes exist, operators may dynamically alter their paths in response to local conditions.
Obstacle handling	Operators can evaluate alternative paths and take detours when roads are blocked.

C.0.5 Traffic Interaction and Task Prioritization

Table C.5: Traffic interaction and task handling for forklifts

Aspect	Description
Overtaking behavior	Forklifts can overtake other human-driven vehicles when space permits.
Intersection rules	Standard right-of-way rules are not consistently applied. Intersections may follow locally established conventions.
Task prioritization	Although tasks are sequenced, informal prioritization by operators occurs to prevent production stoppages.

D

Tugger Train Operations

This section provides a descriptive overview of tugger train operations at Volvo Cars Torslanda. The description is based on interview data.

D.0.1 Application of Tugger Trains

Table D.1: Role and application of tugger trains

Aspect	**Description**
Vehicle type	Tugger trains are operated by human drivers.
Primary use	High-volume, sequential deliveries of pallets and small boxes (*blåbackar*) for repetitive material flows in the A-shop.
Material flow type	Optimized for cyclical and repetitive transport patterns with stable demand.

D.0.2 Milkrun Principle and Cycle Control

Table D.2: Tugger train operating principle

Aspect	**Description**
Operating logic	Tuggers operate according to a Milkrun principle based on a "fixed time, variable quantity" strategy.
Cycle execution	The tugger completes its route regardless of whether the train is fully loaded or partially filled.
System coordination	Cycles are coordinated and monitored by the VCTlog system at Volvo Cars Torslanda.

D.0.3 Routing and Delivery Structure

Table D.3: Routing and delivery characteristics

Aspect	Description
Route structure	Tuggers operate along predetermined sequential loops, often described as "one route, one line".
Stop points	Multiple scheduled stops are defined at Material Addresses (MADs) along the assembly line.
Delivery behavior	Material is delivered sequentially along the route, resulting in extended presence in delivery aisles.

D.0.4 Human Behavior and Traffic Interaction

Table D.4: Human-driven behavior and traffic interaction

Aspect	Description
Driver influence	Tugger train operation is human-driven, resulting in behavioral variability similar to forklift operations.
Route flexibility	Operators can adapt routes and choose alternative paths, for example in the case of blocked aisles.
Traffic rules	Tuggers is overtaking AGVs is prohibited, whereas passing other human-operated vehicles is permitted.

D.0.5 Capacity and Loading Behavior

Table D.5: Capacity and loading characteristics of tugger trains

Aspect	Description
Transport capacity	A single tugger train typically carries 4 to 12 pallets or approximately 50–60 small boxes (*blåbackar*), depending on train size.
Loading strategy	Tuggers are optimized for high-volume transport by maximizing train capacity.
Unload principle	Material exchange follows a "one-in, one-out" principle, where a full pallet or dolly is replaced with an empty one at each stop.

D.0.6 Task Sequencing and Prioritization

Table D.6: Task handling and prioritization

Aspect	**Description**
Task sequencing	Tugger tasks are formally sequenced according to predefined delivery cycles.
Informal prioritization	Similar to forklift operations, informal prioritization rules based on operator experience may be applied to prevent potential stoppages.

E

Overview of literature review

Table E.1: Overview of papers reviewed

Citation	Year	Summary	Themes
[6]	2002	Discusses automated data collection to support DES in the early stage. Prove to reduce model development time and improve accuracy.	Data management for DES
[19]	2008	Proposes a structured methodology for input data management in DES projects. Emphasizes the importance of standardized data processes to improve efficiency, reusability, and model credibility.	Data management for DES
[59]	2025	Explore how standardized data, interfaces, and information exchange enable interoperability, reusability, and automation of simulation models.	Data management for DES **and** Automated Model Generation
[7]	2012	Evaluates automated input data management in DES by demonstrating how increased automation and structured data handling can decrease manual effort.	Generic Simulation Modeling
[52]	2010	Automated raw data collection with automated data processing and introduced the topic of Generic Data Management.	Generic Simulation Modeling
[23]	2023	Provides an overview of DEVS. The paper offers a theoretical foundation for building generic, modular simulation models.	Generic Simulation Modeling
[25]	2020	Presents DELS and automatable DES models for logistics and manufacturing systems.	Generic Simulation Modeling
[53]	2018	Explaining DELS and supporting the development of generic, reusable, and simulation models for logistics.	Generic Simulation Modeling
[48]	2008	Presents for manufacturing simulation interoperability and automation of model construction. It emphasizes that standardized data is crucial for automated simulation model generation.	Data management for DES **and** Automated Model Generation
[46]	2025	The paper emphasizes the importance of standardized data for enabling data-driven and scalable automated model generation.	Data management for DES **and** Automated Model Generation
[49]	2021	Analysis of automated simulation model generation, comparing process- and resource-oriented modeling strategies. The study highlights the role of standardized as an enabler for data-driven, automated DES model generation.	Data management for DES, Automated Model Generation
[47]	2018	The paper demonstrates how consistent data enable automated generation and updating of simulation models, improving synchronization between operational systems and DES-based.	Data management for DES **and** Automated Model Generation
[56]	2024	The paper demonstrates how predefined model structures enable efficient and consistent generation of DES models for complex logistics facilities.	Automated Model Generation
[55]	2022	The paper shows how predefined components and configuration rules can automatically create a valid DES model.	Automated Model Generation
[54]	2019	Analyzes trends in the automatic composition of structures for simulation models in production and logistics.	Automated Model Generation

F

Validation model object functions

The tables used in the "_MaterialStation" frame:

- **t_BOM**: Defines the parts handled by the station, including quantities, order levels, current balance, storage locations, destinations for empty containers, and allowed transporter types.
- **t_Consumption**: Specifies the number of parts consumed for each product variant.
- **InternalTaskList**: Stores the internal tasks related to material handling within the station.
- **t_MaterialOrders**: Contains the generated transport orders based on material demand.

The methods implemented in the Material Station:

- **m_CreateParts**: Generates parts and distributes them to the buffers based on the t_BOM.
- **m_Order**: Creates transport orders when part balances reach the defined order level.
- **m_MaterialIn**: Handles incoming material and updates the internal balance.
- **UpdateAssemblylist**: Updates the assembly logic based on current production requirements.

The tables included in the "_Table" frame are:

- **C_Parameter1-3**: Store the parameters for each transporter type. The first column specifies the transporter type, and the tables include all relevant data for defining transporter behavior. Each transporter is created with an internal table that contains the same information as the corresponding C_Parameter table, ensuring that the parameters are directly available at execution time.

- **C__TaskList1-3**: Define the structure of the task lists used by the transporters and act as the central data structure for handling transport orders. These tables represent the order queue and store all tasks related to transport orders before they are assigned to transporters. The task structure follows the predefined order format described earlier.

- **t__AvailableTransporter1-3**: Contains the list of available transporters that currently do not have an assigned task. These tables are used by the control logic to select transporters for new transport orders.

The methods included in the "_MainModel" and "_Method" are:

- **m__Manager1-3**: Implement the main order control by assigning predefined tasks to transporters in the correct sequence and adapting execution based on transporter type.

- **m__Dot**: Acts as a control gate for the manager methods by ensuring that task assignment only occurs when transporters and tasks are available and no other manager is active.

- **m__TransporterTypes**: Defines and manages the different transporter types used in the model.

- **m__DistanceController**: Controls transporter movement behavior and supports stable execution of transport operations.

- **m__Destination**: Determines the destination of transport orders and supports routing decisions.

- **Init**: Initializes the model before simulation, including setting initial states and parameters.

- **Reset**: Resets the model to its initial state between simulation runs.

G

Auto generator model object functions

- **m_ReadDatabase**: Clears existing nodes. Creates a data table and fills it with data from an external Excel file.
- **m_DeleteMarkers**: Deletes the previous marker table to remove any previously generated markers.
- **m_AdCodeToMarker**: Assigns each marker that has the function MH (material Handelling).
- **m_ConnectMarkers**: Creates connections between markers based on a list, linking each "from" object to its corresponding "to" object from the external excel sheet.
- **m_CreateMarkers**: Creates markers from a created DataTable, sets their position, and saves them with their assigned function.
- **t_MaterialHandelingCodeForMarker**: Runs the Material Handling (MH) logic: loads, moves, unloads a part, then resets for the next task

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