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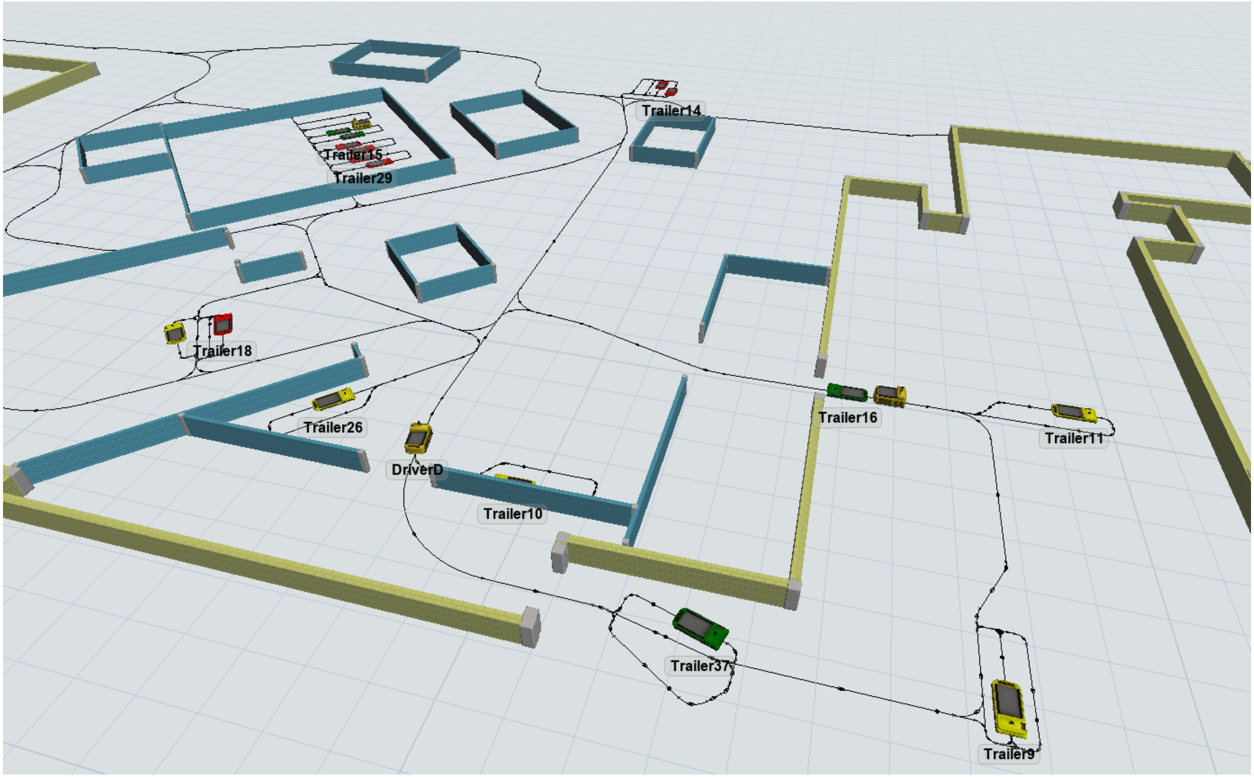

Optimization of In-Plant Logistics Flow Using Discrete-Event Simulation

A Case Study at a Large Swedish Truck Manufacturer

Master's Thesis in Production Engineering

JOHAN BRASCH
OSKAR NILSSON

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

CHALMERS UNIVERSITY OF TECHNOLOGY
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www.chalmers.se

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Examiner: Anders Skoogh, Department of Industrial and Materials Science
Supervisor: Siyuan Chen, Department of Industrial and Materials Science
Advisor: Richard Lindström, Volvo Group Trucks Operations

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Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Image from the 3D representation of the logistics system in FlexSim

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Abstract

The truck industry is undergoing a significant transition, that only will expand in the upcoming years. Greater demands for sustainability and customer demands will force manufacturers to provide a wider range of products. The introduction of electric-powered and gas-powered trucks will increase the complexity and the number of different parts. The Volvo Trucks manufacturing plant in Tuve, Gothenburg, manufactures all variants on a single line. The logistics system at Tuve will face considerable challenges in the upcoming years to handle an increase in part variety.

In this thesis is a Discrete-Event Simulation (DES) model built to analyze and optimize the in-plant logistics system at Volvo. The DES model is used to evaluate the effectiveness of the introduction of a demand-driven pull system as well as optimizing the system in terms of required resources. The positioning of significant locations is compared to each other to limit waste in the system. The DES model will also be utilized to investigate how well the system handles an increase in part variety and predict where investments in capacity are required.

The study showed that the biggest gains in the logistics system are achieved by reducing the required transportation distance. A centrally placed goods-receiving station and empty pallet station reduced the required resources by 40%. A demand-driven pull system created a more even flow throughout the system and reduced the inventory variance at local warehouses. The proposed system is also more capable of handling a future increase in both part variety and part volume while reducing waste.

Keywords: Simulation, Discrete-event simulation, DES, logistics, in-plant logistics system.

Acknowledgements

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Johan Brasch
Oskar Nilsson
Gothenburg, June 2024

List of Acronyms

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

DES Discrete-Event Simulation.

JIT Just-In-Time.

MRP Material Requirements Planning.

Volvo GTO Volvo Group Trucks Operations.

Contents

List of Figures

List of Tables

1
Introduction

This chapter presents the background to this master thesis project, followed by descriptions of the project aim, research questions, and delimitations.

1.1 Background

The truck industry is facing a substantial transition in the upcoming years [1][2]. Increased demand for sustainability has led to the introduction of new products and increased demand for sustainable manufacturing [3]. Premium truck manufacturers need to fulfill the sustainability demands while still meeting the ever-increasing customer demand [4][5]. This will lead to an increased truck model variety. Both electric, gas, hydrogen fuel cells, and traditional combustion engine-driven trucks will have to be manufactured [6].

The premium truck manufacturer studied in this project is Volvo Group Trucks Operations (Volvo GTO). Volvo GTO is one of the leading truck manufacturing company in the world, both when it comes to revenue and brand status [7][8]. This project specifically studied Volvo GTO's manufacturing plant in Tuve, located in Gothenburg [9]. Tuve Plant produces a variety of premium truck models, including electric, gas, and diesel trucks, and has been operational since 1982 [10].

The number of different components involved in the manufacturing processs will duplicate during the upcomming years, due to the reasons mentioned above. The assembly plant in Tuve, which assembles all variants of trucks on a single assembly line is strongly affected by the increase in variety. An increased variety of components increases the demand for storage space, which the assembly line demands more and more of. The factory is built and expanded on several different occasions, which has led to a sub-optimal layout for logistics and material handling. The current method of transporting material from the goods-receiving into local warehouses in the plant is carried out with tugger trains.The tugger trains are also responsible for transporting empty pallets from the local warehouses to the empty pallets station. The tugger trains are currently running based on a schedule, meaning that material is pushed into the local warehouses. The schedule based transportation, and the limited space within the factory lead to inefficient trailer changes, and long and unnecessary driving distances with empty or no trailers (see Figure 1.1).

The last years' technological development within simulation technology has opened

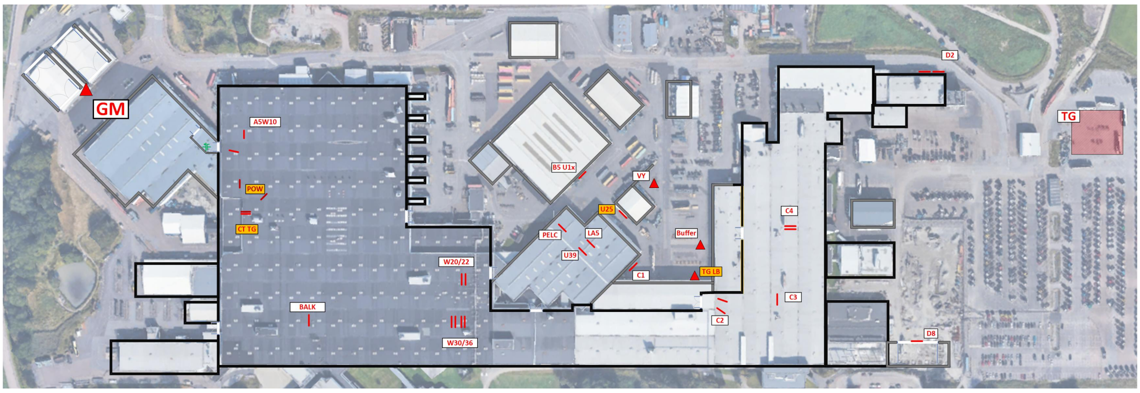

Figure 1.1: Layout overview the Tuve plant.

up new evaluation tools for manufacturing organizations [11]. Traditional methods, based on experience, assumptions, and mathematical models, have resulted in limitations regarding precision within dynamic processes [12]. Utilization of simulation has provided engineers with more accurate estimations and can make more informed decisions [13]. Simulation is according to R.E. Shannon: "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system" [14]. Enabling analysis in a virtual environment provides several benefits, above all, investments can be analyzed beforehand, enabling concurrent engingeering, while still providing a visual picture of the system and evaluating what-if scenarios [15][16].

1.2 Problem Formulation

The global trend of increased part variety in the automotive industry increased the demand on manufacturers internal logistics system regarding reliability, flexibility, and general effectiveness [17]. A future shift regarding sustainability will only excel this trend, especially for manufacturers that aims to provide a wide range of variants. This thesis aims to investigate how manufacturing companies could design their internal logistics systems to tackle future challenges regarding an increase in part variety. This is carried out in the form of a case study.

1.3 Aim

The project aims to investigate an improved solution for how the tugger trains will transport material into the factory. The project will consider both current challenges and future expansions, and how repositioning key locations such as warehouses, empty pallet stations, and buffers can influence the system. Different types of in-plant logistics systems will be looked into, and evaluation will be done on one or more systems using Discrete-event simulation. The project will act as a basis for future decisions regarding logistics layout and factory expansions. Discrete-Event

Simulation (DES) will be used to test and verify the future setup and to compare it with the current system. The model should be able to handle variation and an increased number of parts. It should also test what impacts the location of/distance to goods-receiving, empty pallets shipping and buffers have on the flow, flexibility, and efficiency.

1.4 Research Questions

This project aims to analyze the future in-plant logistics at truck companies, by using the case at Volvo GTO's Tuve Plant. Specifically, this project is looking for a new solution for the tugger train operations at Volvo GTO, which faces the future problems of having more truck models with a large variety of components. This will be carried out with the help of DES software. The following questions will be answered:

RQ1: What type of in-plant logistics system would be the most beneficial within the studied material handling system?

- How could the in-plant logistics system be designed to handle a larger variety of products?

RQ2: How can a DES model be designed to ensure higher flexibility of the logistics system using Discrete-event Simulation?

- How can the system handle an increased variety of parts?
- How does an additional goods-receiving station affect the future material handling in terms of required resources?

1.5 Delimitations

The project will only focus on the in-plant material flow which uses tugger trains in the factory. Alterations to other processes, such as assembly and delivery from external material suppliers, are not considered. The time for the project will limit how many types of logistics systems that will be evaluated using DES, and therefore only one type of in-plant logistics system can be evaluated through DES, to be compared with the present state. The simulation model will be based on historical data, with assumptions on the future increase of material.

2

Theoretical Background

This chapter describes the theoretical framework used throughout the project. It contains theory about discrete-event simulation and the software used in this project, as well as Banks methodology, the methodology used as framework for the discrete-event simulation. The chapter continues with describing in-plant logistics and different principles relevant to the project.

2.1 Discrete-Event Simulation

As defined by Shannon (1975), simulation is "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system" [14]. Simulation therefore acts as a powerful tool regarding analysis and problem solving of real-world problems [18][19]. This includes application areas such as manufacturing applications, health care, construction engineering, and logistics systems. Within a manufacturing context, a simulation model can be used to detect bottlenecks, evaluate layouts, determine buffer sizes, and estimate work-in-progress. The characteristics of DES have made it the most commonly used within the industry.

- ***Dynamic***: A dynamic system represents how a real-world system changes over time. In comparison to a static model, in which time does not influence the model and only represents the system at a particular time [18][20].
- ***Discrete***: A discrete system is a system in which variables change instantly at separate points in time. Continuous system models how the state of a system is changing continuously over time [18]. A state is a collection of variables necessary to describe a system at a specific point in time [20]
- ***Stochastic:*** A stochastic model has one or several random variables as input. The output is therefore also random. Different runs of a simulation may therefore result in different outcomes. In contrast, a deterministic simulation model does result in the same outcome each run [18][20].

2.1.1 Banks Simulation Methodology

A systematic methodology needs to be used to use DES effectively to solve problems and test solutions. A generally accepted methodology is the Banks model, which consists of 12 steps and an iterative process [18]. The steps of Banks methodology are shown in Figure 2.1. The following explanation describes the different steps in Banks methodology in detail [18]. Similar discussions and figures can also be found in other sources [14][20].

1. ***Problem Formulation.*** The simulation study starts with defining the problem and stating it clearly. It is important that if the simulation analyst sets the set of assumptions, they also need to be agreed to by the client. It is also possible to reformulate the problem later in the simulation process.

2. ***Project Plan.*** This can also be stated as "Setting of objectives and overall project plan". The objectives define what questions the simulation study is going to answer. The project plan should define and state what is going to be investigated. Some steps that should be included in the plans are "required time", "personnel that will be used", "hardware and software requirements if the clients want to run the model and conduct the analysis", "stages in the investigation", and "output at each stage".

3. ***Conceptual Model.*** Model conceptualization is made at a simple stage first, and then built towards greater complexity, but still not be more complex than needed to accomplish the purpose of the model. It is recommended that the client is involved in the model conceptualization to increase the quality of the model and also to strengthen their confidence in the implementation of the model.

4. ***Data Collection.*** Between the modeling and collection of data is a constant interchange. As the required data often change, as the model increases its complexity. It's important to understand which type of data needs to be collected, to complete the objects of the study. An understanding of which type of data to be used to validate the simulation model is also essential.

5. ***Coding.*** Coding, or model translation, is to put the conceptual model into a computer-recognizable format, which in this case is a simulation software, to create an operational model. In this project, the software chosen was Flexsim.

6. ***Verified?*** Verification relates to the operational model, and to see if it's performing properly. Complex models can often have verification difficulties, and require a fair amount of debugging. The verification is completed if the logical structure and input parameters of the model are accurately represented. This step is further explained in section 2.1.4.

7. ***Validated?*** Validation is to make sure that the model correlates with the actual system and to ensure there is no significant difference, and otherwise improve the model, usually through calibration. This process is iterated until satisfaction in accuracy is reached. This step is further explained in section 2.1.5.

8. ***Experimental Design.*** A simulation project can have different versions or alternatives to be tested. Everything from different layouts or different parameters to test and compare for optimization. The length of the initialization period, the length of simulation runs, and the number of replications need to be decided for each system design.

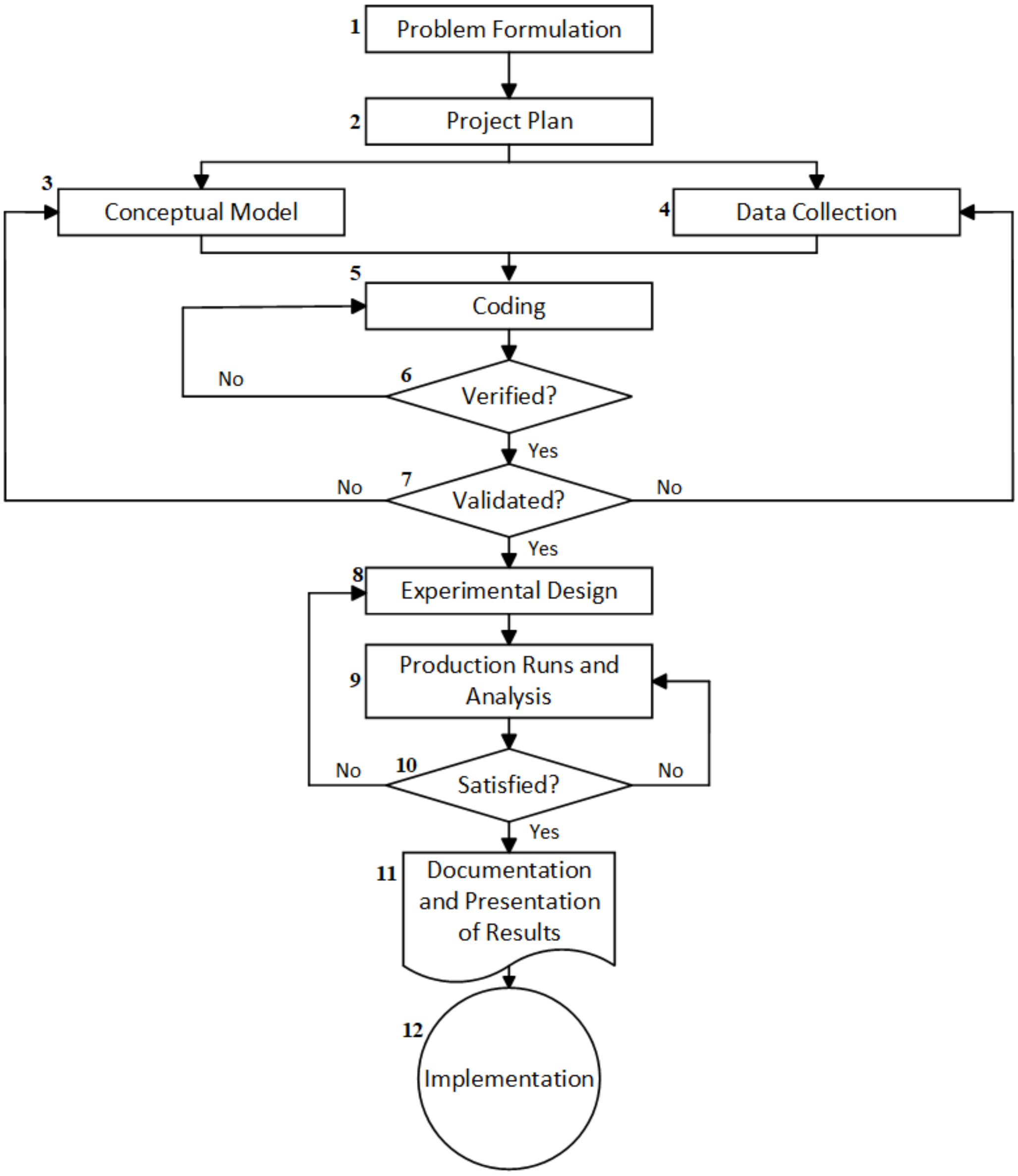

Figure 2.1: Steps in Banks Methodology.
Source: Adapted from [18]

9. ***Production Runs and Analysis.*** Production runs and their following analysis are used to measure the performance of different simulated alternatives.

10. ***Satisfied?*** In this step the analyst determines if additional runs are needed and what design of those runs are going to follow based on the previous anal-

ysis of runs.

11. ***Documentation and Presentation of Results.*** Documentation is made with two different types, program and progress. Program documentation is necessary for creating confidence in the program for decision-making based on the analysis, and enabling future work with the program if it will be used again by different or the same analyst. Good documentation can also help model users understand the relations between the input parameters and output measures and then use that knowledge to change parameters for optimization. Progress documentation is important for having a documented history of the model, which can be used to keep the project on course. It includes decisions made and work done in chronological order. Lastly, the results of all analyses need to be reported in a final report, to allow decision-makers and model users to review the analyses and recommended solutions.

12. ***Implementation.*** The simulation analyst has through the previous steps reported information to the client which will be used to decide on implementation or further work. The more the client has been involved in the process, the chances of successful implementation are increased.

2.1.2 Conceptual Model

Before the coding step in Banks methodology, the development of a conceptual model is required [18]. The purpose of a conceptual model is to express the real-world problem in defined requirements, assumptions, and simplifications [21]. The conceptual model is developed independently from the computational, model, only discussing design alternatives and concepts [22]. The conceptual model also acts as an output of the simulation project. A detailed and structured documentation methodology should therefore be utilized.
Robinson presents five key activities for developing a conceptual model [21]:

- Understand the problem situation
- Determining the modeling and general project objectives
- Identifying the model outputs (responses)
- Identifying the model inputs (experimental factors)
- Determining the model content (scope and level of detail), identifying any assumptions and simplifications.

The development roughly follows this order, but repetition and iterations of several steps occur often due to new information and changes in the problem situation.
The first step, understand the problem situation, is laying a foundation for the other steps. A clearly defined problem derives the following steps and makes sure they align with the purpose [21]. Building understanding consists of observing the real system and identify interactions between different components [18]. Questions should also be asked to people involved with the problem situation to make sure that outputs, understanding and expectations is aligned across all stakeholders [22].

2.1.3 Input Data Management

DES has proven to be a powerful tool, but one disadvantage is the extensive time needed to perform a simulation study [23]. Studies show that 10-40% (31% on average) of the time is consumed by the input data phase, due to high-quality data being crucial for the model [23].

Input data management is defined as the preparation process of all suitable input data parameters, to make it quality-assured and simulation-adapted for the simulation model [23]. It consists of distinguishing the relevant input parameters, gathering the required information to have fitting simulation inputs, converting the raw data to a reliable quality representation, and also documenting the data [23]. The data can be categorized into three different types based on availability and collectability, which leads to different approaches during collection (see Table 2.1) [23][24]. The biggest challenge is the data that falls under category C, which requires estimations. The strategy used for estimations needs to be well-designed and carefully carried out to maintain model quality and can be checked using sensitivity analysis [23][24].

Table 2.1: Three classification types of data [24]

Category A	Available
Category B	Not available but collectable
Category C	Not available and not collectable

2.1.4 Verification

Verification is, as mentioned in section 2.1.1, about building the model correctly. It is about answering the questions: "Is the model implemented correctly in the simulation software?", "Are the input parameters and logical structure of the model represented correctly?" [18]. Overall it's about debugging the program. Eight different techniques can be used for verification and debugging a program [20]. These techniques are summarized in the list below [20]:

1. Don't write the entire program first and debug after. Write the main program and some key subprograms and debug them first, other subprograms can be represented as "dummies".
2. Have more than one person reviewing the program and its logic.
3. Do experimentation runs with different settings and input parameters, and verify the output.
4. Perform a "trace" on the program to check state variables, statistical counters, etc.
5. Run the model under simplifying assumptions when possible, where its true characteristics are known.
6. Observe animations of the simulation where it can be helpful.
7. Compute and compare mean and sample variance of each simulation input probability distribution with historical or desired data.

8. Reduce the amount of programming required by using existing simulation packages in the software.

2.1.5 Calibration and Validation

Validation is to confirm that the model correlates with the process simulated, with enough accuracy relevant for its intended use [20][25]. Calibration is the iterative process when comparing the model and real system, then making adjustments to the simulation, and then comparing again [18]. In order for a simulation model to be fully effective must it be developed for a specific purpose [26]. A complete validation of a simulation model is on the other hand both extremely time consuming and costly. The validation should be suited with the asked questions in mind, and with the right level of detail. The comparison is executed by performing both subjective and some objective tests, and one or more statistical tests [18]. Validation is a continuous activity throughout the model development process and can be carried out with a selection of different techniques at different stages of the development [26]. With this said, Sargent presents two different categories of simulation model validation: Conceptual model validation and operational validation.

Conceptual model validation, or technical validation, is the process of determining if used theories and assumptions are reasonable for the intended purpose [26]. This involves using mathematical analysis and testing to examine wheter the assumptions are reasonable and suitable for the project [25][26]. Determining the detail level of the model is also carried out within the framework of conceptual model validation. The intended logic, mathematical relationships, and causal relationships should also be validated. Two main techniques is utilized to achieve this: Face validation and traces. Face validation involves experts of the system, which evaluates the conceptual model. Traces implies that entities are tracked throughout the model and its sub-models to make sure that logic is correct and that the required accuracy is maintained throughout the model.

Operational validation involves determining if the output of the simulation model is reasonable enough to fulfill its purpose [26]. This is where the main testing and evaluation of the model is carried out and is implemented throughout the entire development of the simulation model. There can be many reasons for poorly validated model: data can be invalid, inaccurate usage of theories, and faulty development methodology. Techniques for operational validation can be divided into two categories: explore model behavior and comparisons of output behaviors. Techniques from both categories should be utilized to obtain a high degree of confidence in the validation [26]. Model exploration behavior implements several practical techniques. The purpose is to analyze the model's behavior, both qualitatively and quantitatively. Parameter variability-sensitivity should usually be used. Comparison of output behaviors involves comparing the models' outputs with either the real system or another model. In general, there are three methods to achieve this: (1) utilization of output graphs, (2) utilization of confidence intervals, and (3) utilization of hypothesis testing. Confidence intervals and hypothesis testing are the most preferable methods since these allow for objective decisions.

When performing the validation process, several techniques can be used. Techniques relevant to the current project are presented below [18][26]:

1. ***Animation.*** Observation of a graphical representation of the models' behavior. For example how material flows through a factory.
2. ***Extreme Condition Tests.*** The logic and structure should be constructed to handle extreme and unlikely combinations of variables. For example, should the utilization of the drivers increase oi only one is available.
3. ***Face Validation.*** Allowing experts and other knowledgeable people to investigate the model and letting them evaluate if the behavior is reasonable. Output can also be evaluated. Sensitivity analysis can be implemented in combination with this to analyze if output behaviors vary as expected when variables are changed.
4. ***Operational Graphics.*** Some performance variables in the simulation are often graphically shown during the running of the simulation. Examples of these are numbers in queues and the utilization of drivers. This can be evaluated when assessing the correct behavior of the model.
5. ***Parameter Variability.*** The technique involves the evaluation of output values when input parameters are varied. The behavior could then be compared to the real system or other ways of identifying expected outputs. The technique could be used both qualitative and quantitative, where subjective judgment can be implemented on the outputs, as well as objective judgments based on numerical analysis.
6. ***Traces.*** Individual entities are tracked throughout the model to analyze how the indented logic is implemented in the computerized model.

2.1.6 DES Software - Flexsim

Flexsim is a "3D simulation modeling and analysis software" developed by Flexsim Software Products, inc., and is a part of Autodesk [27]. It is designed to be user-friendly with "drag and drop controls" to place objects and resources into the 3D model. The models and their 3D visuals are created to scale, making it easier to recognize bottlenecks only by looking at the simulation. Tools for data reporting and analysis are also built into the software [28]. By having the model to scale, CAD drawings can be imported to have the layout exactly as the real system, making transport distances and times accurate to the real system [28].

For model building, Flexsim contains a "Standard Object Library", which contains pre-configured behaviors and different options for customization [28]. The different options can be different properties with already built-in logic and behavior to simulate real-world situations [28]. In addition to the 3D model, to increase the complexity of the model's logic, Flexsim has a feature to build a "Process Flow" [28]. The process flow is used to build a combination of coding blocks, and the user can choose from a variety of pre-built activity blocks to build a more complex logic, similar to a flow-charting environment (See Figure 2.2) [28]. Those activity blocks can be linked to the 3D objects in the model, to for instance trigger the transport of a person or forklift [28]. In addition, the user also can create custom blocks containing a custom code [28]. The Flexsim environment uses flexscript, which is a C++ library that is precompiled [29].

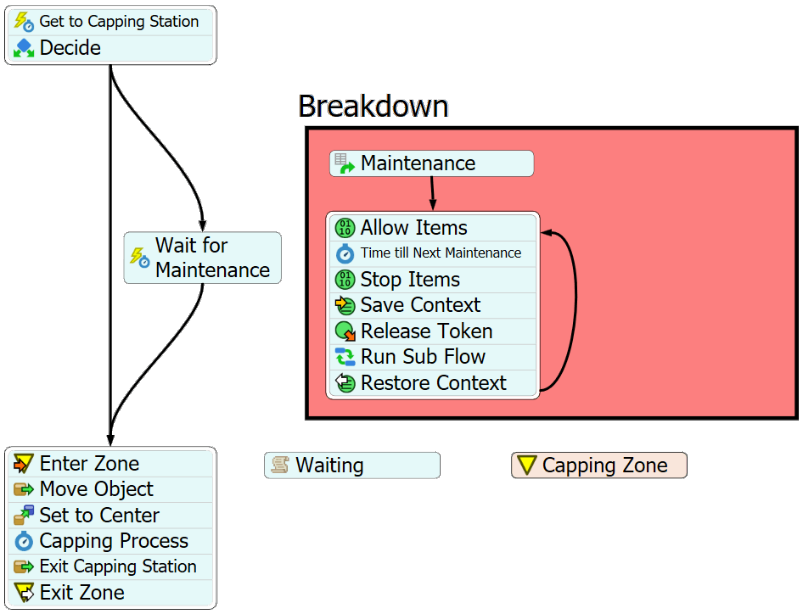

Figure 2.2: Example of a Process Flow in Flexsim [28]

2.2 In-Plant Logistics

"Logistics is comprised of all the operations needed to deliver goods or services, except making the goods or performing the services" [30]. In a manufacturing context entails it the material flow between processing stations in plants and between different plants. A conclusion can then be drawn that there is no value added within logistics and therefore can be defined as waste. Claims has however been made that logistics provides the value of time, place, and presentation [30]. Combining this perception with the concept of Just-In-Time (JIT), originating from Lean manufacturing, provides the following purpose of logistics: "Delivering the material needed, when needed, in the exact quantity needed and conveniently presented" [30][31] . Activities completely located within the boundaries of a plant are defined as in-plant logistics. These activities are under the complete control of one organization.

2.2.1 Internal Logistics Principles

Material handling is the "function of moving the right material to the right place, at the right time, in the right amount, in sequence, and in the right position of condition to minimize production cost" [32]. Material handling has several different goals and purposes however, the primary goal is to reduce the unit cost of production.

Other goals are subordinate to this goal. Estimation claims that on average 50% of total operation costs is represented by material handling [32][33]. To secure efficient material handling have ten principles been established as guidance by the Material Handling Institute [34]:

1. ***Planning Principle:*** All material should be the result of a deliberate plan where the needs, performance of objectives, and functional specification of the proposed methods are completely defined at the outset.
2. ***Standardization Principle:*** Material handling methods, equipment, controls, and software should be standardized within the limits of achieving overall performance objectives and without sacrificing needed flexibility, modularity, and throughput anticipation of changing future requirements
3. ***Work Principle:*** Material Handling work should be minimized without sacrificing productivity or the level of service required of the operation.
4. ***Ergonomic Principle:*** Human capabilities and limitations must be recognized and respected in the design of material handling tasks and equipment to ensure safe and effective operations.
5. ***Unit Load Principle:*** Unit loads shall be appropriately sized and configured in a way that achieves the material flow and inventory objectives at each stage in the supply chain.
6. ***Space Utilization Principle:*** Effective and efficient use must be made of all available space.
7. ***System Principle:*** Material movement and storage activities should be fully integrated to form a coordinated, operational system which spans receiving, inspection, storage, production, assembly, packaging, unitizing, order selection, shipping, transportation, and the handling of returns.
8. ***Automation Principle:*** Material handling operations should be mechanized and/or automated where feasible to improve operational efficiency, increase responsiveness, improve consistency, and predictability.
9. ***Environmental Principle:*** Environmental impact and energy consumption should be considered as criteria when designing or selecting alternative equipment and material handling systems.
10. ***Life Cycle Cost Principle:*** A thorough economic analysis should account for the entire life cycle of all material handling equipment and resulting systems.

2.3 Lean Logistics

Lean logistics is the logistics dimension of lean manufacturing originating in the Japanese car manufacturer Toyota [30][35]. Lean has become the standard manufacturing principle across several industries. The foundation for lean operations is based on a selection of principles, which should be implemented across entire organizations. The principles are: value, value stream, flow, pull, and perfection [31]. The goal is to eliminate all types of waste within operations to achieve a fully efficient flow of value.

2.3.1 Waste

In Lean concepts, waste elimination is one of the cornerstones of operation excellence. Waste is defined as an activity that consumes resources without creating any value for the end customer [31][36][37]. Waste is recognized in three different types: Muda (Waste), Mura (unevenness), and Muri (Overburden). All three types are connected and need to be considered to achieve a fully optimized system.

Muda
Muda is the most recognized type of waste and is expressed as activities utilizing time, money or other resources without creating any value to the end customer [36]. The seven traditional types of Mura are the following:

1. Overproduction - Producing more than what is currently demanded by the next process or customer. Contributes to the other six.
2. Waiting - Waiting for upstream material, failed equipment, etc.
3. Conveyance/transportation - Unnecessary movement of parts and products.
4. Overprocessing - unnecessary or incorrect processing
5. Inventory - unnecessary holding of material in warehouses and buffers.
6. Motion - Movements that are non-value-adding and unnecessary.
7. Correction - Inspection and rework.

Mura
Mura means unevenness and refers to variation in workload. It has its origin in fluctuating production or an irregular production schedule. [38]. It is also caused by batch logic, where utilization wants to be maximized for key resources and equipment [36]. This makes it necessary to have a capacity that meets the highest level of production, even if the average requirements are far less. Mura and Muru are then created to compensate for the unevenness.

Muri
Muri means overburden of equipment or people. Overburden over natural limits leads to a decreased ability to perform and results in inadequate safety and quality [36][38]. The exact opposite of overburden can also be identified as Muri, underutilization of people and equipment. There are three main causes of Muri:

1. Poorly organized workstation
2. Lack of standardized work
3. Mura

2.3.2 Pull & Flow

The concept of flow is a core belief and guideline for efficient operations according to Lean principles [38]. Flow is the concept of material and information moving through a value stream without stopping, only involving value-adding activities [31][39]. A high degree of flow implies a reduction in different types of mudas, such as waiting, overprocessing and inventory. Buffers can be reduced [31][35]. To achieve a fully functional flow of material and information is a full standardization of processes required. The operation should also aspire to implement a one-piece flow across the entire value chain. Both of these objectives can be found in the internal logistics principles presented in section 2.2.1.

Another core principle in lean operations is the concept of "pull". Pull is the activity of only providing customers (or the next process activity) with material or services when it is required or when it is requested [30][31][37][38]. The ideal desired state is a fully functional JIT flow, where the next process activity gets what they want when they want it, and the right amount they want. In contrast to a scheduled push method, a pull system reduces the need for buffers and reduces overproduction. The method also replaces the need for complex scheduling systems, saving resources and the possibility for mistakes [39].

2.3.3 Design of an In-Plant Logistics System

The design and arrangement of an In-Plant Logistics system depends highly on the case at hand, and its specific requirements and conditions. Some principles and working methods, which are mentioned in sections 2.2.1 & 2.3, have however been proven to lead to long-term success. A major source of costs in a supply chain is inventory [40]. It impacts customer responsiveness and the goal of many operations is to reduce the amount of inventory kept over time. The JIT inventory system concept has become popular, as well as other Lean principles and methodologies. In general can two operational strategies be identified within in-plant logistics, push and pull. Push strategies are implemented in companies with a high degree of certainty and control [41]. A push assists managers in planning their production to meet customer demands and what capacity they are required to have to store the receiving stock. A Material Requirements Planning (MRP) and an accurate production master plan are often required within a push system [40]. The motives of a push strategy are to minimize the cost of purchasing and to be able to predict resource allotment. This leads to a more complex system and is based on anticipation and assumptions of future requirements and customer demands. In a pull system is the delivery of material controlled by demand. It is more of a response on customer orders, and often includes a kanban system which signals the need for more material [32][40]. A pull system is less complex and mainly focuses on maximizing the service, in contrast to minimizing costs [41]. When striving to reduce costs in a production operation is it said that an improvement in flow automatically will reduce costs [32]. A shorter flow in terms of time will reduce the need for space, a simpler methodology is required, and visual management is easier to maintain.

When designing an in-plant logistics system is there three aspects that needs to be considered. The storing of parts, the delivery to the assembly line, and the return of empty pallets. Regarding the storing of parts are two generic alternatives available: centralized storage near the receiving point, or decentralized storage closer to the assembly line [17]. A centralized storage implies longer distances to the assembly line and in some cases requires deliveries in larger lots and batches. In contrast to a decentralized storages does it however reduce the required floor space closer to the assembly line. Regarding the delivery to the assembly line is in general three methods available. Push system, a pull system, and milk-runs [17][37]. Push system runs on a set schedule designed to maintain an even flow to the assembly line and to fully utilize the transporting equipment. A push system is governed by the material demand of the assembly line, meaning that material is only delivered when needed. A milk-run is a system that provides material to a selection of delivery points within the same driving sequence. It usually also follows a schedule and results in deliveries occruing in set intervals. The final aspect, return of empty pallets, has two general methodologies: a return flow integrated in the forward flow, or an exclusive flow for the return flow.

3

Methodology

The methododology of the project followed the concept of Banks methodology for simulation. An initial understanding was achieved with the help of a qualitative study to create a conceptual mapping of the current situation. A simulation model based on the conceptual mapping was then developed within the modeling software FlexSim. Lastly, an improvement and experimenting phase was conducted with an iterative methodology.

3.1 Qualitative Study

A qualitative study was conducted to answer the research questions presented in section 1.4. The qualitative study consisted of a stakeholder analysis, a literature study, observations, and work-shops. The purpose of the qualitative study was partly to get an initial understanding of the project and to formulate a problem definition, but also to acquire insight into how a new logistics system could be designed to best suit the project at hand.

3.1.1 Stakeholder Analysis

The concept of stakeholders and stakeholder analyses has become a highly popular management principle within recent decades [42]. The concept of stakeholders is subject to many different definitions in different contexts. In general, it can however, be defined as a *person, or a group of people, who is involved in an organization in a way that they can affect, or is affected by the organization's objectives* [43][44]. A stakeholder analysis is a process of identifying stakeholders within a project, and then categorizing and evaluating the roles of the stakeholders [42][43]. A stakeholder analysis is often associated with great success in the startup of a project, to identify and define problems and questions. This is especially important in cases that involve a larger amount of participants and different points of view.

In the initial stages of the project, the desired outcomes and purpose of the project were unclear and undefined. A stakeholder analysis was then conducted to identify stakeholders that may be affected or may be affected by the outcome of the project. Different departments within the organization had different perceptions of which problems that were the most critical, and what improvements that would bring the most benefits. An analysis regarding a problem definition was thereby conducted.

An analysis regarding how stakeholders could aid the project was also conducted to make sure that the best possible outcome was realized.

The initial step of identifying stakeholders started by interacting with people responsible and who are involved with the current logistics system. The analysis took the form of short semi-structured interviews where the interviewee got the opportunity to share their opinions and knowledge regarding the project. The interviews included a question if the interviewee knew someone else that may bring value to or be affected by the project. A summary of the stakeholder analysis is presented in Table 3.1. The table also presents the role of the stakeholders, and whether the stakeholder contributes to the realization of the project, or will be affected by the results. A stakeholder can also be a group, or a department, as seen in the table.

Table 3.1: Summary of the stakeholder analysis

Realisation Stakeholders	**Role**
Project Members	Developing the simulation model and new system
Logistics Engineering Department	Knowledge and data providers about the system
Goods-Receiving Management	Interested in a more effective system. Knowledge about the current goods receiving operations
Results Stakeholders	**Role**
Logistics Engineering Department	User of the simulation model
Tugger Train Drivers	Affected by the real life implementation
Goods-Receiving Management	Affected by the real life implementation

The stakeholder analysis acted as a foundation for the rest of the qualitative analysis regarding observations and interviews.

3.1.2 Observations

To get an understanding of the current system, and to gain an understanding of demand for a future system were observations carried out throughout the project. The purpose of the observations was to collect information and insight into the system without including any biases. The methodology also avoids the involvement of past behaviors and personal attitudes of people involved in the system [45]. The observation method was mainly used during the mapping of the present state of the logistics system. To be able to compare, and identify similarities and differences across the system was a structured observation method implemented. A form was designed where data and observations were noted in a structured way. This made it possible for comparisons and also simplified the documentation of the observations. The observations were carried out as non-participant observations, in contrast to participant observations [45]. The observers were then not interfering with the current process, intending to observe a normal state of the process.

3.1.3 Interviews

To get a deeper understanding of the purpose and functionality of an improved system, and what questions a simulation model should answer, several unstructured interviews were carried out. The selection of interviewees was based on the stakeholder analysis. More precisely, the interviewed people were: the tugger train drivers, managers of the tugger train drivers, and logistics engineers. Unstructured interviews were utilized since the purpose of the interviews was to gain insight and a more general view of the situation [45][46]. The interviewee is then allowed to take control of the conversation and can cover areas they find important and relevant. Questions asked were for example: "Can you explain how the delivery sequence is designed?" and "What are the strengths/weaknesses of the current system?".

A semi-structured group interview was conducted with the logistics engineers. The semi-structured procedure allowed the interviewees to freely elaborate on the topics presented by the interviewer [46]. This method was selected due to the superior knowledge of the interviewees compared to the interviewers. The purpose of the interview was to lay a foundation for a conceptual model for the simulation and to fully establish the requirements of the simulation users. The interview was divided into four sections, in which each member initially provided input individually followed by a group discussion for each section. The four sections were: (1) What are the benefits of the current system?, (2) Identify problems with the current system, (3) What are the causes for the problems?, and (4) Identify possible concepts (and sub-concepts) for a new system. Topics and ideas were then grouped and ranked to identify the most important and impactful conclusions. The software tool Mural was utilized for documentation during the interview [47]. All interviewees could then be involved in the documentation during the interview.

3.2 Present State

This section describes the present state analysis, with descriptions of the problem formulation and system definition. It goes on to describe the method for finding a suitable in-plant logistics system.

3.2.1 Problem Formulation

In line with the first step in Banks methodology for simulation was a problem formulation formulated. The formulation was based on information gained during the stakeholder analysis. One of the main goals of the project was to find a better type of in-plant logistics system and validate the solution with a DES model. The aim of the model were also to be able to test different parameters and new layouts for the system.

One of the main challenges for the project was to create a system that can handle the future increased variety of parts due to an increasing number of product variants. To succeed in this was a model developed to investigate both how the logistics system works, as well as evaluating key locations for warehouses, and other important locations. The stakeholder analysis, observations, and interviews provieded the project with different guidelines and ideas for where different locations could be repositioned, which the logistics team at Tuve wanted to be able to test and have as decision-making support. The interviews also clarified that the introduction of an additional goods-receiving location should be investigated. Another challenge was to make reasonable assumptions on how the future parts proliferation will affect the future in-flow of pallets needed to be made to create a DES model that could be validated.

3.2.2 System Definition

The tugger train transportation is responsible for the transportation of material from a goods-receiving station to local warehouses within the assembly plant and the transportation of empty pallets out of the plant to an empty pallet station. A tugger train consists of a tugger tractor and three trailers.

Material transported by the tugger trains is different truck components manufactured by subcontractors. The material arrives on pallets with trucks to a goods-receiving station, where pallets are unloaded and loaded onto trailers, and each set of trailers is assigned to a specific local warehouse in the plant.

The driver driving the tugger is currently following a schedule for when each route is supposed to be driven. The driver picks up the set of trailers at a specific time at the goods-receiving. The tugger train is then driven to its dedicated delivery point at the local warehouse. Depending on the available floor space at the delivery point is there either a two-bin solution in which one set of trailers with material is delivered and one set of trailers with empty pallets are collected in the same area, or in places with restricted floor space, the set of trailers with the material is left at a trailer switching area before the empty pallet trailer is collected at the delivery point. The empty pallet trailer is then transported to the trailer switching area, where the tugger switches to the trailer with material, drives it to the delivery location, and then returns to pick up the empty pallet trailer. After this process, both in the two-bin and switching area cases, the empty pallet is transported to an empty pallet station, where empty pallets are loaded onto trucks to be delivered away from the plant. A set of empty trailers is collected at the empty pallet station and delivered to the material starting position at the goods-receiving station.

Some scheduled routes are only responsible for transporting empty pallets to the empty pallet station from locations in the plant. In these routes, the driver drives to the collection point at a specified time, collects a trailer with empty pallets, drives it to the empty pallet station, and finally returns an empty set of trailers to the pick-up point in the plant.

Many routes are subject to exceptions from the standard driving sequences. Buffers are added in some cases, delivery of empty pallets are delivered to other places than the main empty pallet station, and drivers can be instructed to collect material at other places than the main goods-receiving station by phone, and then skip a route in the original schedule.

Since the material is loaded onto trailers immediately upon arrival at the goods-receiving station, the material is pushed to the local warehouses, and no significant storage is carried out at the goods-receiving station. The variance in incoming material is therefore handled in the local warehouses. The material loading at the goods-receiving station, the unloading at the delivery points, and the loading and unloading of empty pallets are carried out by forklifts.

3.2.3 In-Plant Logistic System

One of the aims of this project was to find a suitable in-plant logistics system, that can fulfill the needs that the studied material handling system has and will have In the future. Different approaches for a study were conducted to choose an in-plant logistic system to test through DES. It was made by conducting a literature study, and having workshops together with different relevant people at the company to get their point of view on what could work or not, in addition, the mapping of the system through "go and see" was used to get a broader perspective as well. The combined studies gave both an organizational perspective and a technical perspective.

During the literature study, different in-plant logistics systems were evaluated. The strategies that mainly were looked into were the optimization of a push system and conversion to a pull system [40][48]. In combination with the literature study, workshops were also conducted as mentioned. The workshops were made with an open approach, meaning that specific logistic systems were discussed. The focus was to brainstorm and discuss everything that is good with the current system, but mainly finding problems with the current system and problems that could occur in the future with an increased number of parts and limited space. With that in mind, the reasons for the problems and different possible and desired solutions were identified. The results from the workshops were used together with the literature study to find a suitable and the most promising in-plant logistics system to then evaluate using DES.

3.3 Model Building

One of the big parts of the methodology to be able to answer the research questions was the building of the DES model [18]. This section describes that process, which followed Banks simulation methodology. First, the creation of the conceptual model is described, followed by the data-gathering process. Later, the process of actually building the model is described, which consists of multiple parts such as building a 3D model, creating tools in Flexsim's toolbox, and building the process flow which is the logic controlling the simulation model. Lastly, the validation of the model-building is described which completes the model-building phase.

3.3.1 Conceptual Model

Before the model-building phase, a conceptual model was developed. The purpose of the conceptual model was to express the current real-world problem in defined requirements, assumptions, and simplifications. The conceptual model was developed independently from the computational model, only discussing design alternatives and concepts.

Table 3.2: Summary of the conceptual model

Area	Description
Overview	• Analyze how the internal material transportation can be designed to be more flexible and efficient. Performance will be measured in the ability to fulfill the demand for material from the assembly line
Reasons for Improvements	• Utilizes space inside the factory • Material is pushed to local warehouses • Silo mentality • Long driving distances • Locked/inflexible solution
Parameters	• Number of Drivers • Number of Trailers • Location of Goods-receiving • Location of Empty Pallet Station • Material Order Rate • Batch control • Re-order Point
Output	• Delivery Rate • Backlog of orders • Inventory level in warehouses • Time driven with each load • Inbound inventory capacity
Input	• Tugger Speed • Material Demand • Delivery points • Max Load Trailers • Distances/Layout • Empty Pallet Handling • Loading/Unloading Times • Breaks/End of Day

The initial steps of the conceptual modeling were to get an understanding and insight into the current situation and wanted outcomes of the project. The starting point for this was the defined problem formulation and stakeholder analysis. Further, first-hand data was collected through visits, interviews, and a go-and-see (Gemba walks). Current states, solutions, and problems were documented in a systematic way. Current driving routes were mapped, and documented, and questions were asked to drivers while they were driving the routes.

The formulation of the conceptual model followed the Activity Based Conceptual modeling framework [49]. The entire formulation of the conceptual model is presented in Appendix A. The formulation includes an overview of the purpose of the project, the reasons for improvements, parameters, experimentation, output, and inputs to the simulation model. It also includes a simulation logic framework (see Figure 3.1) and a list of model content. The model content list presents different concepts considered in the simulation project with a description and assumptions/simplifications in the simulation.

Desired outcomes and areas of use were derived via a workshop with the clients and domain experts. The workshop identified and evaluated different strengths of the current situation, weaknesses with the current situation, reasons for the weaknesses, and different concepts that will be evaluated and how performance should be measured. The outcome of the workshop then laid a base for an initial version of a conceptual model. The development of the model is based on the methodology presented in section 2.1.2. The process followed an iterative methodology in which clients and domain experts were continuously involved regarding assumptions, simplifications, and input data. Principles presented in section 2 were also considered in the development of the conceptual model.

To create a system as flexible as possible, an order and booking concept was developed. An order is placed from delivery points within the factory and drivers (tugger trains) and trailers are booked for the delivery of the order. To achieve traceability and measurement, positions are continuously updated. Types of loads, and orders are also continuously updated throughout the driving sequence. The entire simulation framework is presented in Figure 3.1.

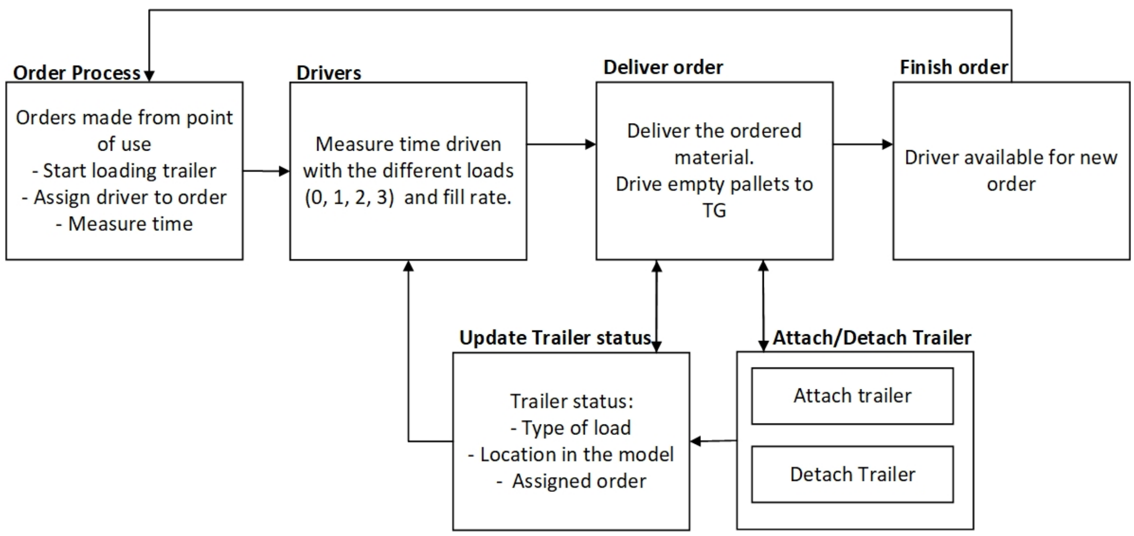

Figure 3.1: A framework explaining the simulation logic

3.3.2 Data Gathering

An initial mapping and understanding of the current situation was achieved through a collection of data and qualitative information from the physical world. A go-and-see approach, based on the lean concept of "GEMBA walks" was pursued. This was done by interviewing factory floor operators, and responsible managers, and in-person observations. Relevant people to interview was identified and connected with the help of the company supervisor. The documentation followed a structured methodology using forms and maps to investigate the situation. A visual mapping is desirable and digital versions was created using diagram drawing tools.

3.3.3 Building the Model

This section describes the process of building the model and mainly covers steps 5 to 6 in Banks methodology [18]. All the steps were made in an iterative process, starting with a few simplified components and logic structures, and progressively expanding to incorporate additional complexity with each iteration. The different steps in the modeling are described in different sections describing different parts of the model such as the 3D Model and Process Flow.

3.3.3.1 3D Model

For making the model visual as well as utilizing objects with pre-configured behavior, a 3D model was built. The 3D model was built to represent the real-world layout of the factory and was built to scale with correct distances etc., except for the tuggers and trailers which were enlarged to be more visual (See Figure 3.2 and 3.3). This was, as mentioned, done using objects from the "Standard Object Library". Firstly, the outer walls of the factory were built to visually see the layout easier. Then the road network for the tuggers was built, mainly by using objects called AGV Paths together with Control Points. These objects could then be configured with data to represent the real world, for instance, travel speed at different locations.

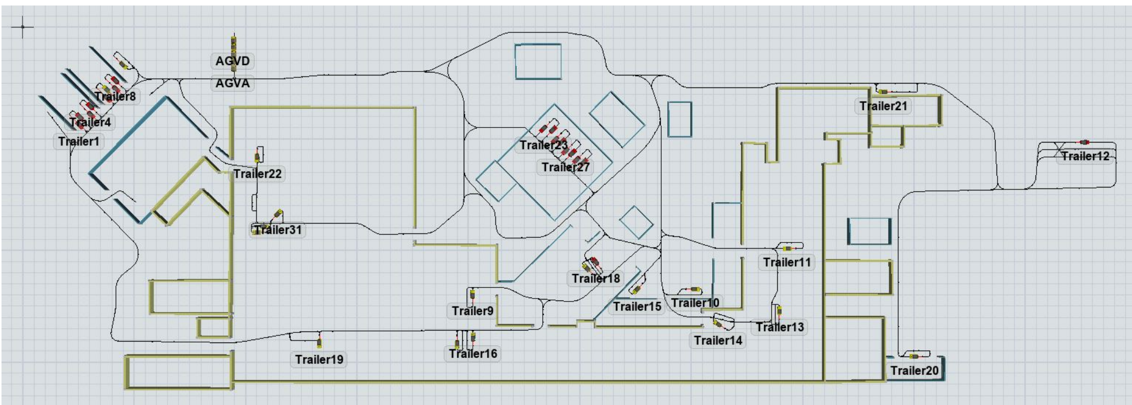

Figure 3.2: Top view of 3D Model of the plant in Flexsim

The tuggers were represented as objects called AGV's in the model, but in the real system, the tuggers are driven by workers. The AGV's were chosen due to them having different functions and behaviors that were useful for the model. Figure 3.3 shows a close view of an AGV (DriverA) driving with a connected trailer loaded with material (the green color of the trailer means that it is loaded with material).

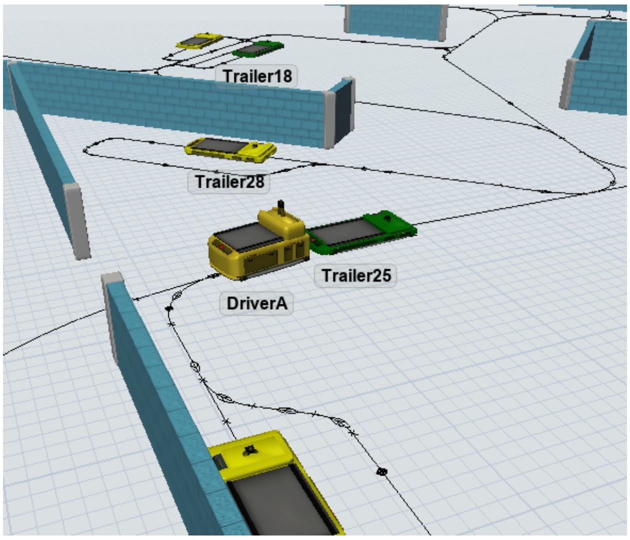

Figure 3.3: Close view of Driver and trailers in the 3D Model of the plant in Flexsim

3.3.3.2 Toolbox

The toolbox handles tools and components utilized in the simulation. These can be utilized across the entire simulation and are useful for tracking data and storing information.

Global Tables

Global tables were used when data needed to be retrieved, tracked, and updated across the entire simulation model. Global tables had four main areas of use: trailer tracking, driving instructions, description of routes, and input data.

The trailer tracking table ("TrailerTable") acted as a tracking and booking system for the trailers in the simulation model. It tracks:

- The position of each trailer.
- What type of load it currently had (material (3), empty pallets (2), empty trailer (1))
- Which route it was currently driving
- The booking status declaring if it was loading, unloading, driving, booked, or free.

The TrailerTable made it possible to track each trailer, and also ensured that a trailer only could be booked on one route at a time.

The driving instructions table describes the driving sequence of each route. It stored the next destination of the driving sequence, what activity it should do on arrival (attach/detach trailer), and what type of load (3, 2, 1, 0) it should have after the current step. 9 of 14 of the routes followed the same driving sequence and, therefore utilized the same global table, but the others required a modified driving sequence table.

The description of routes table was utilized as a base for the driving sequence table. It stored the drop-off point, the location where the material will be delivered, and which driving sequence that should be utilized. The routes table also controlled which routes that are active in the simulation. Only the routes mentioned in the routes description table are driven in the simulation.

The input data tables were used to incorporate input data from the real-world system into the model. This includes material demand data from the assembly line in the plant and inbound delivery of material to the plant. This was stored in two different tables: "PartTable", and "InboundData". PartTable included the part number for each component, the type of pallet it was transported on, and how often a pallet was demanded on the assembly line. The InboundData table included the part number of each component, when it was delivered, and how much that was delivered each time.

Global Variables

Similar to global tables, global variables can be accessed from the entire model. In this project were the global variables used to handle trailer positions at the delivery and pick-up locations. Each variable was defined as the data type array, where each element was a control point in the 3D model. The first element is the reference control point for the location. The rest of the following elements are trailer slots at the delivery location. The array was used in the process flow logic to identify which slot the driver should drive to, depending on whether it should collect a trailer or find an empty slot to deliver the trailer to. See Figure 3.4 for the global variables associated with the goods-receiving station.

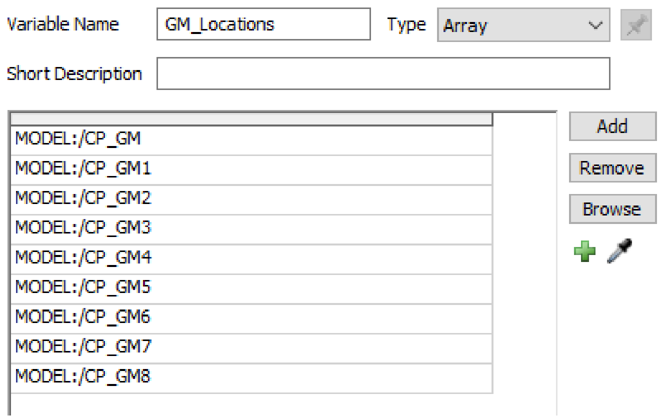

Figure 3.4: Global variables for the trailer slots at the goods-receiving station

3.3.3.3 Process Flow

The process flow governs the logic of the simulation and controls how different 3D objects and activities interact with each other. The process flow utilizes tokens, acting as activities that flow through the process flow and trigger different activities. This section describes the smaller building blocks and processes that create the full process flow.

Initial Stock and Order Start

The process block that starts the whole simulation is Initial Stock and Order Start (see Figure 3.5). The process is made to create pallets in initial stock, both in the inbound warehouse and in the local warehouses. In the local warehouses, the initial stock was set to one pallet of each type from the global table "PartTable", see section 3.3.3.2 for description, and the initial stock in the Inbound Warehouse were set to one week's demand. This was made to not have a problem with missing material at the start of the simulation before new inbound deliveries came in. This process also creates the tokens in the "Material Usage and Order Process" block, which starts the order process for the simulation.

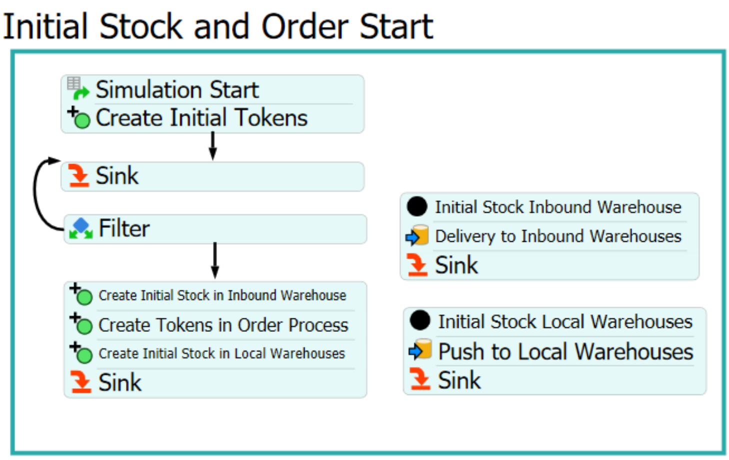

Figure 3.5: Initial Stock and Order Start Process Block in ProcessFlow

Material Usage and Order Process

The material usage and order process block represent the consumption of components by the truck assembly line, and a demand-driven pull system controls the transportation of material (see Figure 3.6). The demand is based on historical data from the global table: "PartTable", see "Global Tables" in section 3.3.3.2. The demand was calculated in pallets, not in single articles, to simplify the simulation.

In the simulation block is an order placed at a determined "re-order point". The rest of the time required for the consumption of an entire pallet is then run before a pallet is removed from the local warehouse. The placed order is placed in a batching activity, where it awaits orders with the same destination. The order proceeds to the loading section when the capacity of a tugger train is reached or after a set max time after the first order of the batch, called "batchcontrol".

Trailer Loading and Send Order to Driver

The "Trailer Loading and Send Order to Driver" process block (see Figure 3.7), simulates the activities of identifying an available trailer at the goods-receiving station,

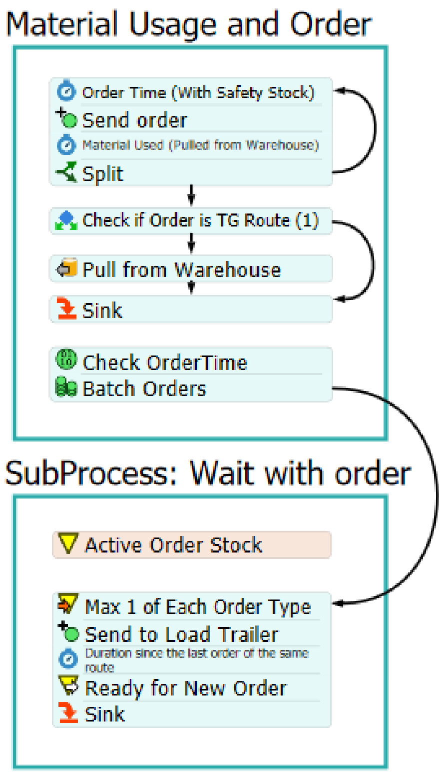

Figure 3.6: Material Usage and Order Process Block in ProcessFlow

and loading the trailers with pallets from the batched order from the "Material Usage and Order Process" block, see previous section.

Firstly, the block controls if the current route is an empty-pallet route, or if it is a material delivery route. If it is an empty-pallet route, the order is immediately moved to the "Drive Route" block (see next section). If it is a material delivery route, the orderdoes initially check whether the required material is present in the inbound warehouse. If not, the order stops and waits for the material to arrive. If material is present, a free trailer is identified and booked at the goods-receiving station. A forklift is then allocated to load the order to the booked trailer. The order is then transferred to the block "Drive Route" (see next section).

Drive Route (Attach and Detach)

The "Drive Route" process block and the "Attach/Detach Trailer" process block control the traveling of the drivers, the coupling and uncoupling of trailers, and the identification of the next destination (see Figure 3.8). The logic is mainly controlled by the "DrivingSequence" table (see "Global Tables" in section 3.3.3.2). The block initially gets assigned a driver, if one is available. The code then loops over the rows in the active driving sequence table until it has finished its assigned route. The driver is then released and is available to be booked by a new order.

Loading and Unloading Trailer

After a trailer is delivered and detached from the driver, the "Loading/Unloading

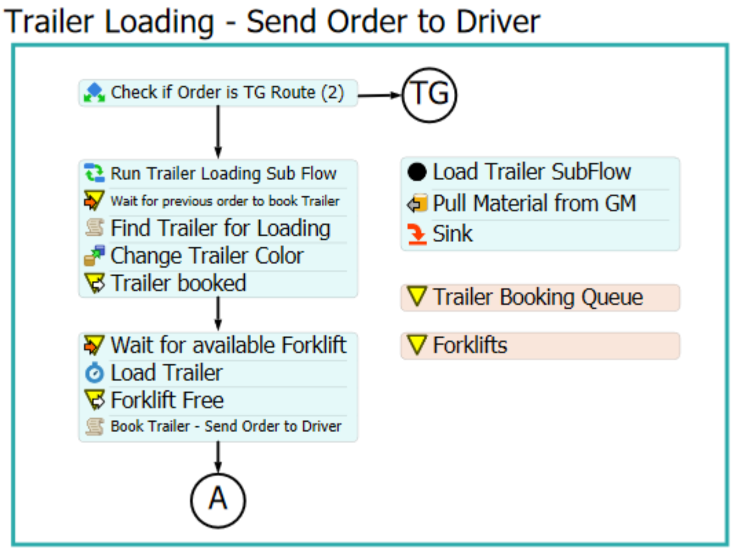

Figure 3.7: Trailer Loading - Send Order to Driver Process Block in ProcessFlow

Trailer" process block is run (see Figure 3.9). The first step is to identify whether the trailer should be unloaded or loaded, and with which load it should be changed into. When trailers are delivered with material to a local warehouse in the plant, the material is firstly unloaded from the trailer before empty pallets are loaded onto the trailer. If the trailer is detached at the empty pallet station, the empty pallets gets unloaded from the trailer, and the trailer status is set to one (1). If a trailer is delivered to an empty pallet collection location in the plant, only empty pallets are loaded to the empty trailer. If the trailer is detached at a goods-receiving station, both unloading and loading are skipped since it waits to be loaded until an order is placed and it's loaded in the "Trailer Loading and Send Order to Driver" process block.

When a trailer is unloaded at a local warehouse increases the stock level of that warehouse with one pallet of each of the articles included in the order. This concludes the delivery of material to a location in which it is demanded.

Inbound Delivery

Inbound delivery of parts (see Figure 3.10), was based on one year of historical data. The data was simplified by grouping the deliveries into a time slot of the week, because most of the deliveries of the same type, for instance, part number or supplier, were delivered at the same time of the week each time. By doing this, the simulation could use a scheduled source that delivers material to the inbound warehouse for a whole week at the correct times with some variation using a continuous uniform distribution function. Repetition of that schedule for each week generates the correct amount of inbound parts each year. These deliveries could also be scaled up using a parameter, to be able to test an increase of volume.

Breaks and End of Day

To fully represent the real-world system, breaks, shift changes and end-of-day stops

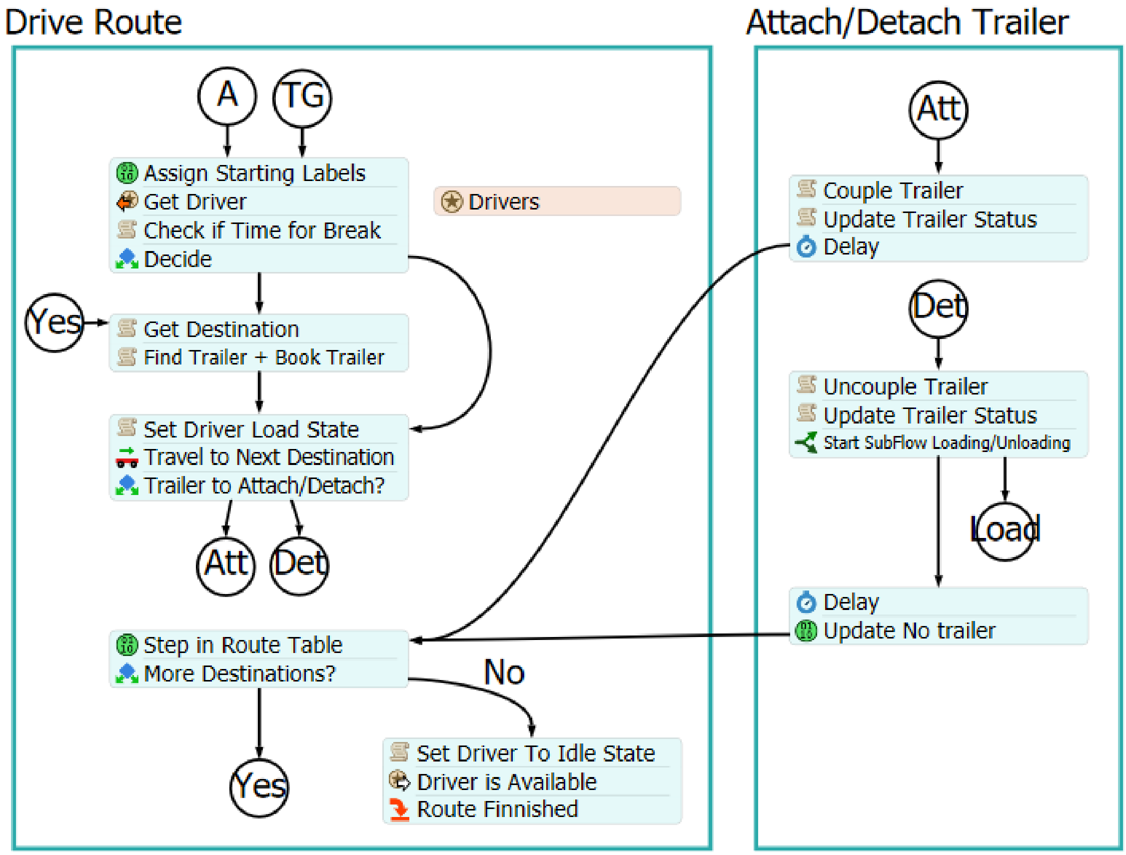

Figure 3.8: Drive Route Process Block in ProcessFlow

are considered. A "time schedule" is created which stops the material consumption, and drivers finish their current route and then stop transporting trailers. This is controlled with a process block that stops, stores context, and then holds the orders during breaks and off-schedule times. The orders are then returned where they left before the break or at the end of the day (see Figure 3.11).

3.3.3.4 Dashboard/Presentation of Results

To analyze the simulation, a selection of variables was tracked during the simulation. These were all presented in a dashboard in the simulation software. The presentation of variables were presented in graphs, tables, and pie charts. The purpose of the dashboard was foremost to measure and evaluate the performance of the system within different areas, but also to be used as a tool for verification and validation of the system. The measures presented in the dashboard were also used when deciding upon a warm-up time. The following measurements were considered:

- **Warehouse content over time:** A graph displaying the inventory level of each local warehouse over time.
- **Goods inbound warehouse content over time:** A graph displaying the inventory level of the goods-receiving warehouse over time.
- **Driver state allocation:** A pie chart displaying how much time each driver

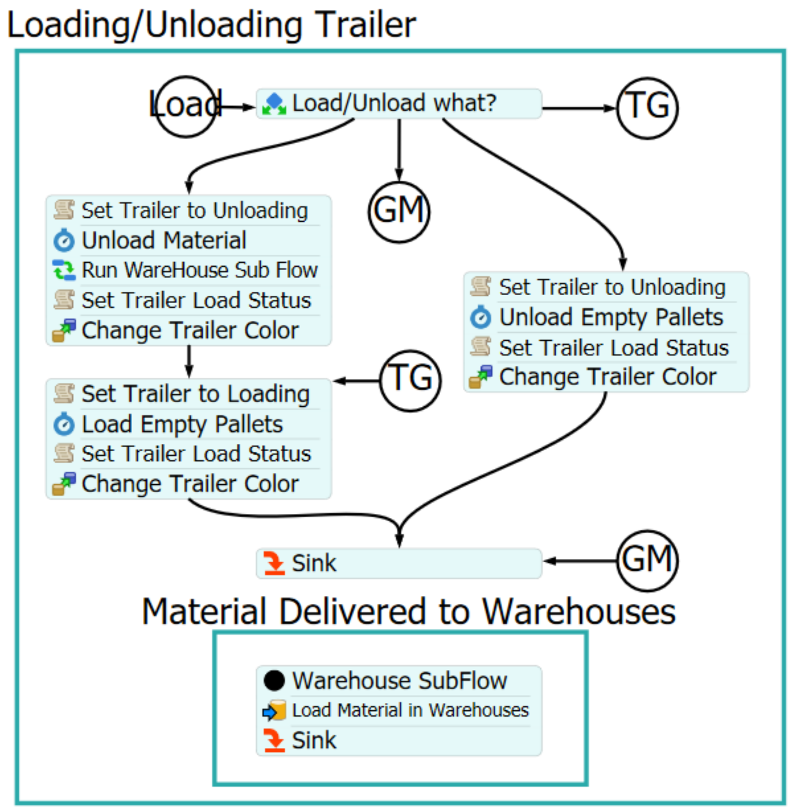

Figure 3.9: Loading/Unloading Trailer Process in ProcessFlow

is spending with a specific type of load or if the driver is idle

- **Number of back orders at each time:** A graph showing how many orders the system was not able to deliver on time over time
- **Total wait time for trailer:** The total time spent waiting for an available trailer that can be loaded at the goods-receiving station.
- **Total wait time for driver**: The total time spent waiting for an available driver to drive an order.

3.3.4 Validation

The seventh step in Banks Methodology is the Validation step and completes the model-building phase, see Figure 2.1 in section 2.1.1.

3.3.4.1 Conceptual Model Validation

The purpose of the conceptual model validation was to ensure that correct assumptions were made and that the model logic was reasonable and was an adequate representation of the real-world system. The purpose of the conceptual model validation was not to make sure that the conceptual model was a complete representation of the real world, but rather that the conceptual model is detailed enough to fulfill its intended purpose.

Figure 3.10: Inbound Material Deliveries Process in ProcessFlow

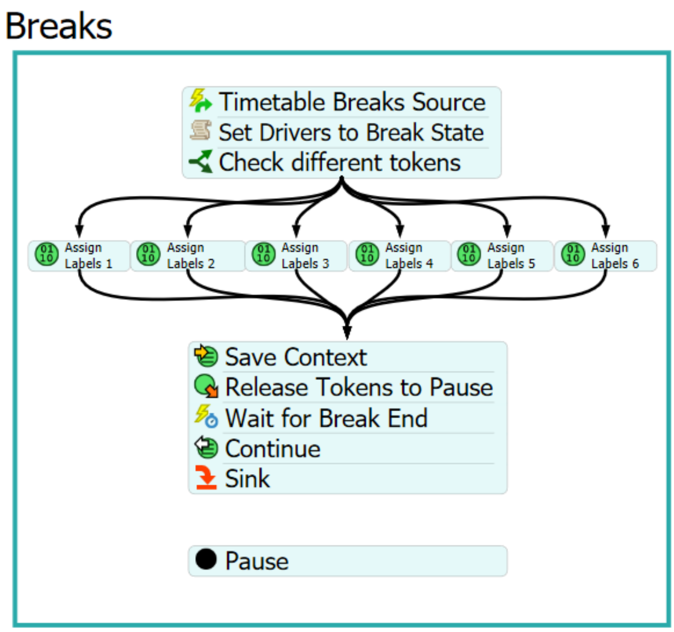

Figure 3.11: Break Process in ProcessFlow

The validation of the conceptual model was carried out in an iterative manner, as presented in Figure 2.1. The project group continuously evaluated assumptions and intended logic throughout the entire model-building process. Methods used in the conceptual model validation were face validation and traces. Face validation involved the receivers of the simulation study in the development of the conceptual model. These were judged to be knowledgeable of the real-world system and the desired outcomes of the project. Inputs were collected by conducting workshops and questioning the stakeholders throughout the project. Stakeholders were also invited to read and give feedback on the conceptual model documentation. The use of traces included tracking entities (parts and pallets) throughout the model and evaluating if the correct logic was implemented. All different variants and cases were considered to make sure that the logic functioned as intended.

3.3.4.2 Operational Validation

Operational validation involves determining if the simulation model behavior and outputs are accurate enough and are aligned with the intended purpose of the model. Similar to the conceptual model validation (see section 3.3.4.1), the operational validation was carried out continuously throughout the model-building process.

Sargent presents a selection of validation techniques that all apply to test operational validation [26]. The project utilized a selection of these when ensuring the operational validation of the simulation model: animation, extreme condition test, face validity, trace, operational graphics, and parameter variability.

Since the simulation software provided a 3D-model with realistic 3D representation, see section 2.1.6 & 3.3.3.1, the animation technique was applied throughout the model-building process. The graphical representation of the simulation was observed and analyzed to ensure that objects, such as drivers and trailers, moved according to the intended logic.

The dashboard function in the simulation software presented in section 3.3.3.4 provided the project with a selection of different operational graphics that were utilized to validate the model. Primarily used graphics included graphs presenting the utilization and driving states of the drivers, the inventory content at each delivery point, and the number of back-orders. The visual representation of the process flow, presented in section 3.3.3.3, was also helpful in identifying anomalies and when the flow logic was not moving as expected. For example, queues and delays could appear when not expected. The operational graphics technique was often paired with other techniques to identify the effects and consequences of the implementation of other techniques.

As mentioned above, and in section 3.3.3.3, the token-governed process flow did enable visual tracking of the logic of the simulation. The tracing technique was utilized within these tokens to track activities. The logic could then be tested and evaluated when tracking the values of a token. Special cases and all types of variants could thereby be validated towards the intended purpose of the logic.

Extreme condition tests and parameter variability were utilized in conjunction to evaluate the logic and the models' expected capacity. This meant that parameters were set to different values, and the output changes were compared with expected effects. To fully test the robustness of the model was extreme tests conducted. Parameters were set to values deemed to be unrealistic and extreme to test whether the model was producing the expected results. For example, the number of drivers was reduced to one, and the demand for materials was increased by 300%.

Finally, face validity was utilized across the validation process. Logic and Figures were presented to stakeholders to evaluate if the logic worked as intended and would fulfill the intended purpose. The experience and knowledge of the project team were also an important asset regarding face validation.

3.4 Experimental Design

The purpose of the experiments in the project is to answer the research questions. The experiments consisted of two main experiments, each with a set of sub-experiments where optimal parameters were varied. Each experiment was performed separately, but the earlier experiments laid the foundation for the latter.

To measure the performance of the system was a selection of response measures utilized. The main measure was the occurrence of a backlog when the material was not delivered on time. The goal or the criteria for this measure was to never have any backlog at any point in time [30]. Other measures were also taken into consideration but were not the fundamental basis for decision-making. These were: the utilization of each driver, the inventory level at each warehouse, and the inventory level at the inbound warehouse.

For each experiment, several factors are varied to find an optimal solution. The main cost drivers in the system, the number of drivers, and the number of trailers varied with each sub-experiment. Both of these factors are aimed to be kept at a minimum, while still fulfilling the criteria of no backlog. The reason for minimizing the number of drivers was to reduce the running cost of the system, and the reason for minimizing the number of trailers was to reduce the required floor space in the factory, and not to provide any excess capacity. Additionally to these factors, two other parameters were also varied: "batchcontrol" and "Re-order point". See Material Usage and Order Process in section 3.3.3.3 for further description.

Before the experimental process commenced, decisions regarding the initialization period, length of simulation runs, and number of replications to be made for each run were made [18]. These decisions were made based on the nature of the system and the input data. Breaks and end-of-day activities were considered to create a system that represents the real-world system. In other words, were non-production hours included in the simulation runs. Weekends are however not included in the simulation. The total simulation time was set to about 2 months (1440 hours) to make sure that all variation was included in the simulation. The initialization period is set to 2 weeks (336 hours) to reach a steady state. Regarding the number of replication runs, each experiment consisted of 8 replications. A summary of the simulation settings is presented in Table 3.3.

Table 3.3: Settings used during experiments

Simulation Time:	1440:00:00
Initialization Period:	336:00:00
Replications:	8

The range of each parameter is derived from a combination of interviews with stakeholders and shorter empirical tests in the simulation model.

3.4.1 Experiment 1: Additional Goods-Receiving Station

The objective of the first experiment was to evaluate the effects of introducing an additional goods-receiving station. Three cases were evaluated in this experiment. One case included the present state situation, with a single goods-receiving station located at its current location. The second case included another goods-receiving station, located in the middle of the plant. Finally, was the relocation of the empty pallet station also investigated. The distance to the empty pallet station was defined as a parameter. The division of the routes between the goods-receiving stations is based on the location of the delivery locations. The reason for conducting this experiment was to answer Research Question 2, see section 1.4. The experiment intended to evaluate the impact on required resources with the introduction of a new goods-receiving station, which could act as a decision basis when deciding upon whether the investment is profitable in the long run.

The range of the No. Drivers were derived to see if the required amount could be decreased to reduce costs. The number of trailers was based on how many trailers that could be attached to a tugger simultaneously. The "batchcontrol" factor, and the "Re-orde point" were based on short tests within the simulation to identify a reasonable range.

For each experiment, were a set of sub-experiments conducted. In each sub-experiment, the number of drivers, the number of connected trailers, "batchcontrol", "re-order point", and "distance to empty pallet location" varied. A summary and the range of each parameter are presented in table 3.4. A total of 432 sub-experiments were conducted.

Table 3.4: Experimental design for experiment 1

Parameter	Range	Step Size	No. of Entries
No. Drivers	[3-6]	1	4
No. Trailers	[2-3]	1	2
Batchcontrol [sec]	[3000-7000]	500	9
Re-order Point [%]	[20-80]	30	3
Distance to Empty Pallet Location [m]	[1-201]	200	2

3.4.2 Experiment 2: Increased Volume

The purpose of the second experiment was to investigate how well the system could tackle an increase in part variety and volume, and identify at which level of increase an additional driver was required. The result of the experimentation contributed to answering research question two, presented in section 1.4. As mentioned in section 1.1, will the number of variants increase by 100% during the coming 10 years. Experiment 2 mimicked the increase, and analyzed how well the system could handle the increase, and what resources should be expanded to fulfill the future demand.

The volume was represented by a factor in the range of 1-1.8. This was used for different increases in volume. The experiment was, similarly to experiment 1, built up by sub-experiments. Each sub-experiment once again investigated the required number of drivers and trailers to avoid any backlog in the local warehouses.
The derivation of the ranges for the parameters in the simulation follows the same reasoning as in experiment 1, see section 3.4.1. The "volume factor" is based on stakeholder interviews, claiming that the number of articles will double in the coming years. The range of drivers is based on the wish to investigate when an additional driver is required due to an increase in volume.

To limit the required experiment runs was experiment 1 taken into consideration. An assumption was made that the required number of drivers and trailers would only increase with an increase in volume, and therefore experiments with a lower number of drivers than the result in experiment 1 were discarded. A summary and the range of each parameter are presented in Table 3.5. A maximum total of 1080 sub-experiments will have to be conducted.

Table 3.5: Experimental design for experiment 2

Parameter	**Range**	**Step Size**	**No. of Entries**
Volume Factor	[1.2-1.8]	[1.2, 1.4, 1.6, 1.7, 1.8]	5
No. of Drivers	[3-8]	1	6
No. of Trailers	[2-3]	1	2
Batchcontrol [sec]	[3000-7000]	500	9
Re-order Point [%]	[30-80]	30	3

4

Results

This chapter presents the results of the project. First, the result from the present state analysis, followed by the design of the logistics system, and lastly the result from the experimental study.

4.1 Present State Analysis

Figure 4.1 shows the locations of the delivery-, and pick-up points in the plant. It also shows the location of the goods-receiving station (GM) and the empty pallet station (TG). The blue lines symbolize the road network that the drivers utilize when driving between the different locations. Notable is the positioning of the goods-receiving station and the empty pallet station. Being positioned on each end of the plant leads to long driving distances to maintain a circulation of trailers and in-between routes.

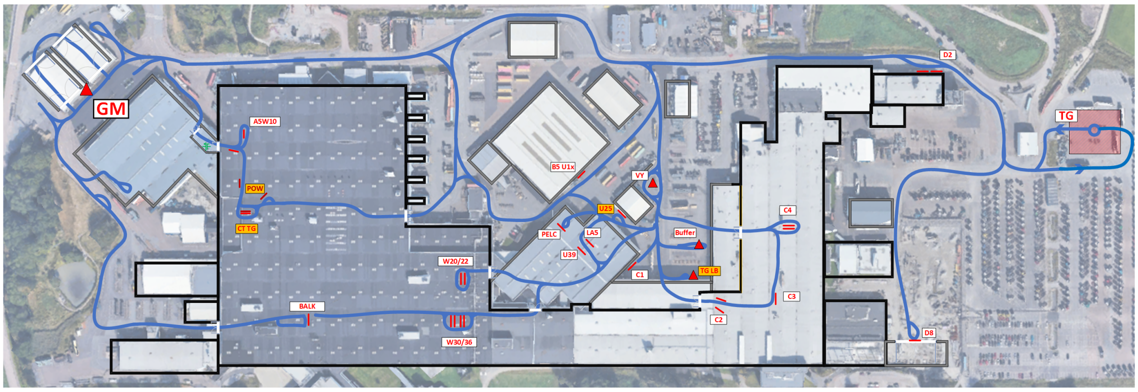

Figure 4.1: Map over the Tuve plant with its road network and material locations.

4.1.1 Categorization of Routes

The tugger trains are operating 17 different routes. Five of these are only transporting empty pallets out of the plant. The other 12 are transporting material to local warehouses. To track the tugger train activities during the different routes four different types of loads: Material, Empty Pallets, Empty trailer, and No trailer. Each category was measured in terms of driven distance. Mapping of the tugger train routes, and matching them with maps of the plant was used as the foundation for the distance measurement. The number of couplings was also measured during each route, which is how many times a trailer is attached or detached. A summary of the mapping is presented in Table 4.1. Figure 4.2 shows a summary of an entire day, where the frequency of each route is taken into consideration.

Table 4.1: Mapping of the routes in the present state

Mapping of the Routes					
Route	**Couplings**	**Material**	**Empty Pallets**	**Empty Trailer**	**No Trailer**
A5W10	6	11%	44%	43%	2%
B5U1X	10	53%	0%	47%	0%
BALK	8	10%	31%	19%	40%
C1	10	28%	27%	38%	7%
C2	12	29%	25%	32%	14%
C3	10	28%	26%	33%	13%
C4	8	31%	30%	39%	0%
CTTG	4	0%	51%	49%	0%
D2	6	40%	11%	49%	0%
D8	6	46%	15%	38%	0%
LBTG	3	0%	25%	23%	51%
POW	4	0%	8%	8%	85%
U25	4	0%	31%	24%	45%
U39	4	0%	40%	38%	22%
W20/22	10	28%	27%	31%	15%
W30/36	6	33%	31%	36%	0%
W30/36 PELC	6	9%	50%	40%	0%

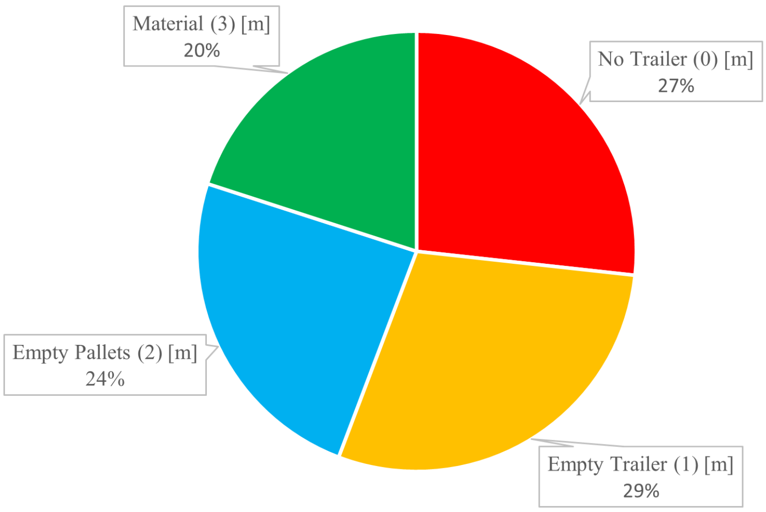

Figure 4.2: Summary of the division of different types of loads driven during a single day.

The present state analysis shows that only 20% of the total driven distance is an immediate value-adding activity of transporting material to a desired location. 24% of the distance is transporting empty pallets out of the plant. Though this does not contribute to an increased value for a customer, or providing the assembly line with the material, is this categorized as a necessary activity. Empty pallets will have to be transported away from the plant to make room for new material. The two final categories, empty trailer, and no trailer, are neither value-adding nor necessary and want to be kept at a minimum. The final two are however involved in maintaining a circular movement of trailers and traveling between different routes.

To be noted is that for a traveled distance to qualify to the material category it only requires that a single pallet is loaded into a trailer. The mapping does not consider the fill rate during both the transportation of material and empty pallets.

4.1.2 Driving sequences

The type of route, material delivery or empty pallet transport, and the difference in conditions at each location have led to a variety of different driving sequences for each route. The difference can be seen when observing the difference in the number of couplings in Table 4.1. The standard procedure is to follow a two-bin system, with two trailer slots which makes it possible to deliver one set of trailers next to a set of trailers with empty pallets. This limits the distance driven without any trailer (a 0-load). A lack of floor space near the plant's local warehouses has led to the introduction of a switching area (VY) outside the factory. A schematic of some sequences is presented in Figures 4.3, 4.4, and 4.5. W30/36 represents a material delivery sequence with a functional two-bin system, where material can be delivered and empty pallets can be picked up at the same place. POW represents a sequence that is solely handing empty pallets. C2 represents a sequence in which a switching area and a buffer outside the plant are utilized.

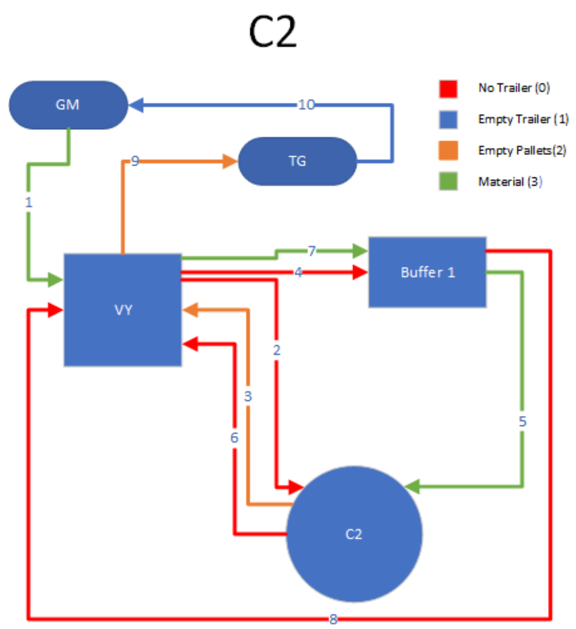

Figure 4.3: Schematic of the C2 delivery sequence.

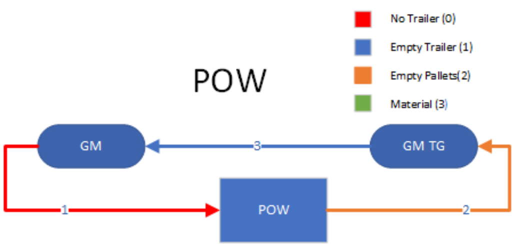

Figure 4.4: Schematic of the POW empty pallet sequence.

Figure 4.5: Schematic of the W30/36 delivery sequence.

4.2 Designing the Logistics System

The design of the proposed system included several large-scale changes to the initial system. This meant that a general design and layout of the system had to be decided, which could not fully be taken into consideration with DES experimentation. Section 3.2.3 presents the tools and methodology used to create concepts and principles for the new system.

4.2.1 Observations and Workshop

This section discusses the results from observations during the project as well as conclusions drawn from interactions with stakeholders, both via interviews and workshops. These stakeholder interactions initially acted as an introduction to the project, to establish the purpose of the project. The interactions did however mainly include different problems, areas for improvements, and requirements of a future system. The main problems of the current system were the following:

- Lack of floor space in the plant.
- Bad traceability of the material.
- Inflexible system, difficult to rebalance.
- Overflow of material near the assembly line.

Often mentioned is the limited space close to the assembly line. With an increased variety of parts and an assembly line with an increased demand for floor space in the plant, should an improved system limit the need for floor space, and be able to keep inventory low close to the assembly line.

Requirements for an improved system were the following:

- Simpler process.
- Able to handle variety in incoming material.
- Able to handle an increase in part variety.
- More flexible regarding capacity.

The future increase in part variety is a strong driver for an improved delivery system. The current process is often criticized for being too complicated with several individual solutions for special cases. An improved system is desired to be simpler than the current one, making it more comprehensible and easier to understand.

Apart from the above-mentioned problems and requirements must the improved system utilize the same equipment as the current system. The current delivery process, where each driving sequence only supplies a single delivery point, should also be maintained. A milk-run alternative is therefore not being considered. An introduction of additional goods-receiving will also be evaluated. The location of this goods-receiving is pre-determined to be in the central area of the plant.

Observations and communication with the drivers of the tuggers showed the amount of special solutions that solely depended on the knowledge and expertise of the driver. It also highlighted the long distances driven without any value-adding activity. An improved system should thereby, as mentioned before, be more standardized and increase the utilization rate of the drivers.

4.2.2 System Design

The final design of the system was based on a combination of input from stakeholders and established literature, see section 3.2.3. Principles and methodologies identified in the literature were initially identified and then matched with the results from the observations and stakeholder interactions.

The core purpose of the logistics system is to deliver the material needed when needed, and in the exact quantity needed [30]. This statement is the leading principle and purpose of the designed system. To achieve this objective is a pull system designed, in which the material delivery to local warehouses in the plan is need-based. A flow which is following a JIT principle will reduce the need for storage space within the plant, and also limit the risk of overflow in the local warehouses since the material is only delivered when needed.

The delivery sequence will also be more standardized and simpler. Each delivery will utilize a two-bin system, in which material can be delivered, and empty pallets can be collected at the same location, at the same time. This is according to the second internal logistics principle presented in section 2.2.1.

Regarding the empty pallet return flow, a combination of methods will be utilized. All material delivery sequences will include a return flow of empty pallets, meaning that it will be included in the forward flow. Exclusive sequences for empty pallets will also be utilized. This is unwanted, but since the tugger train operations are responsible for transporting a larger amount of empty pallets than what they deliver pallets with material into the factory, this is required to fulfill the demand.

4.3 Experimental Study

This section presents the results from the experimental study described in section 3.4.

4.3.1 Experiment 1

As mentioned in section 3.4, the system was required to be able to handle the demand from the local warehouses with no backlog or late deliveries. Sub-experiment 1 intended to identify the required values for the initial case with the current goods-receiving station, compared to the required values for the new goods-receiving station in sub-experiment 2. A repositioning of the empty pallet station together with the new goods-receiving station was also evaluated in sub-experiment 3. The results are presented in Table 4.2.

Table 4.2: Requirements for the different sub-experiments with different goods-receiving locations and empty pallet station locations.

Sub-Experiment	No. Of Drivers	No. Of Trailers	Batchcontrol	Re-order Point
1	5	3	4000	50%
2	4	3	5000	50%
3	3	3	6500	60%

All factors were aimed to be kept at a minimum to reduce costs and achieve a smooth flow. As seen in the sub-experiments 1 and 2 in Table 4.2, the new goods-receiving station requires a lower number of drivers. The relocation of the empty pallet station reduced the required numbers even further to 3, a reduction of 40%. Since the number of drivers is the main driver of cost, the new goods-receiving location is more favorable in terms of lower running costs.

Regarding how the drivers are utilized for each case is a summary of all drivers presented in Figure 4.6.

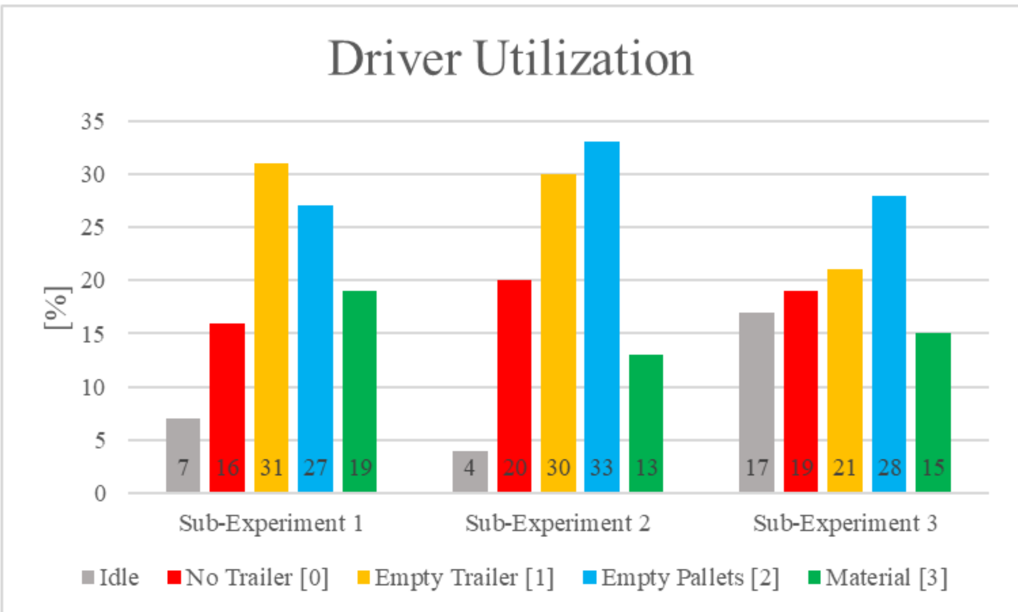

Figure 4.6: Summary of the driver utilization for the three sub-experiments

The inventory level for the local warehouses and the inbound warehouse at the goods-receiving station is presented in Figure 4.7 and 4.8. The Figures represent the current goods-receiving and empty pallet station positions.

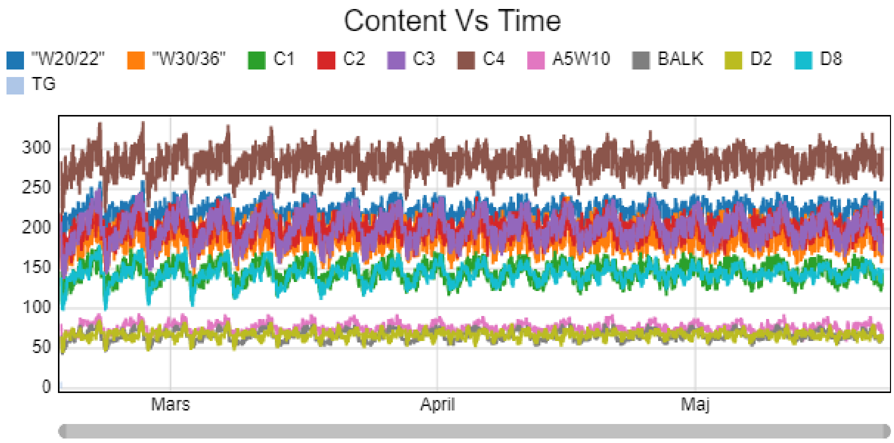

Figure 4.7: Inventory levels in the local warehouses with the current goods-receiving and empty pallet station position.

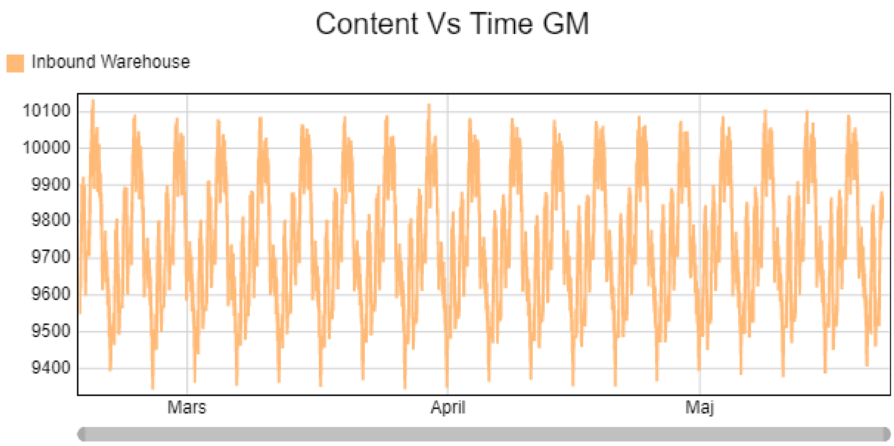

Figure 4.8: Inventory levels at the inbound warehouses with the current goods-receiving and empty pallet station position.

4.3.2 Experiment 2

The purpose of experiment 2 was to investigate how the system can handle an increase in volume. The results will provide the model user with information regarding when to further invest in more personnel and resources and to determine what costs are associated with an increase in volume.

As mentioned in section 3.4, experiment 2 was based on the results from experiment 1. The reasoning for this was to limit the required amount of replications, and thereby the required time for the experiment. Replications with the Capacity factor = 100, have already been run in experiment 1, and a fewer number of drivers than

4 were never tested in experiment 2.

The results of experiment 2 are presented in Table 4.3. The results show that an additional driver is required with an increase in volume by 40%, 60%, 70%, and 80%. Figure 4.9 presents how the number of required drivers changes with the capacity factor.

Table 4.3: Results from Experiment 2

Capacity Factor	100	120	140	160	170	180
No. of Drivers	3	3	4	5	6	8
No. of Trailers	3	3	3	3	3	3
Batchcontrol	6500	6000	6000	6000	6000	6000
Re-Order Point	60%	60%	60%	60%	60%	60%

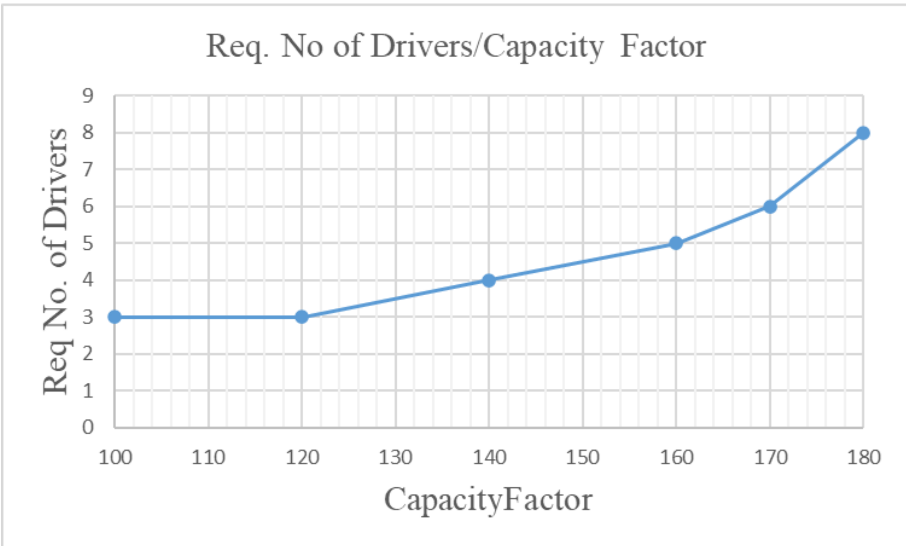

Figure 4.9: Graph presenting the required number of drivers as a function of the capacity factor

The inventory level over time for the local warehouses is presented in Figures 4.10 and 4.11. The figures represent the case for when the capacity factor is set at 120% and 180%. The inventory level over time in the inbound warehouse for the same capacity factors are presented in Figures 4.12 and 4.13. The required capacity at the inbound warehouse in terms of pallets is presented in Table 4.4. The capacity is calculated as the difference between the maximum and minimum inventory levels at the inbound warehouse.

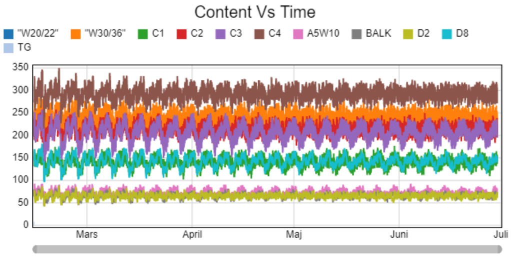

Figure 4.10: Inventory level in the local warehouses with a volume capacity level of 120%.

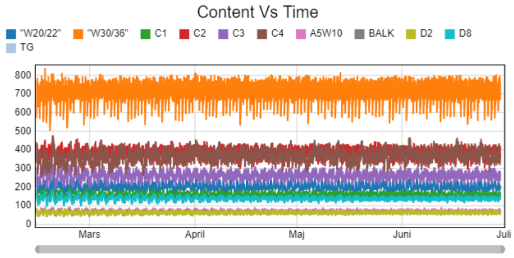

Figure 4.11: Inventory level in the local warehouses with a volume capacity level of 180%.

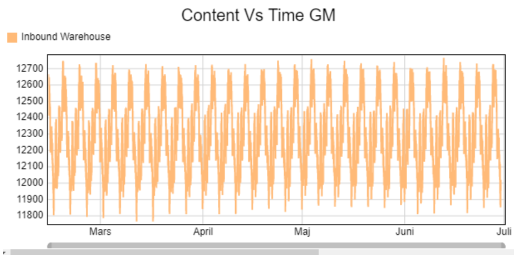

Figure 4.12: Inventory level in the local warehouses with a volume capacity level of 120%. Showing a maximum amplitude of 967.

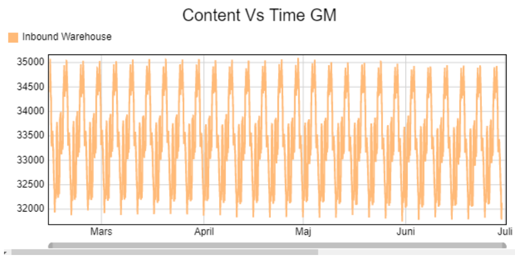

Figure 4.13: Inventory level in the local warehouses with a volume capacity level of 180%. Showing a maximum amplitude of 3155.

Table 4.4: The required capacity of the inbound warehouse in terms of pallets for different capacity factor values

Capacity Factor	100	120	140	160	170	180
Req. Inbound Warehouse Capacity	757	967	1324	1908	2523	3155

5 Discussion

An ever increasing level of customer- and demand has lead to a substantial increase in customization within the automotive industry [17]. This has pressured companies internal material handling system with to increase their effectiveness to handle the increased complexity and demand of an increased part variety. This project has been carried out as a case study at a truck company which profiles as provider of highly customised heavy duty trucks. Effective and useful methods in this case would therefore also be applicable in other cases. Worth mentioning is however that every case and material handling system is unique and requires their own analysis and problem solving.

General takeaways for a broader industry can however be identified. An increase in part variety leads to an increase number of storage slots in warehouses to be able to keep all varieties available in short notice. A demand driven pull flow in combination with a centralized inbound warehouse limits the pressure on local warehouses and storage close to an assembly line. Shorter transport distances also enables a more responsive and flexible material handling, which is beneficial in most cases, especially with an increased part variety. This findings aligns with the material principles presented in section 2.2.1 [34]. Especially the principles regarding standardization, work, and space utilization

The DES model created in this project is closely associated with the current case, as it should be to answer the questions asked in this project [26]. The logic that governs the model is however created in a general way, meaning it could be applied to another case wanting to implement a similar standardised delivery methodology. The limiting factor that bounds the current model to the specific case is the physical layput in the factory that is represented in the 3D-model (see section 3.3.3.1). An useful approach regarding a general utilization of DES is that the logic should be generalised with flexible parameters. This enables a model to be broadly implemented in different contexts while still being useful. Important differences from the current case project and a more generalized implementation is however the level of detail and assumptions made. This will have to be considered and evaluated when identifying the needs and purposes of a DES study.

5.1 Research Questions

RQ1: What type of in-plant logistics system would be the most beneficial within the studied material handling system?

Results from the qualitative study, including a literature study, observations, and interviews with the case company proved that a demand-driven pull system is the most effective logistics system for the studied material handling system. A pull system is better suited for handling variations in the inflow of material. A pull system is also less complicated for drivers since all sequences are standardized with the utilization of two-bin systems at the delivery points. The in-plant logistics system is further discussed in section 5.2.

RQ2: How can a DES model be designed to ensure higher flexibility of the logistics system using Discrete-event Simulation?

The first experiment in the experimental study exhibited how big an influence the transportation distance has on the effectiveness of a logistics system. The experiment showed that a centrally positioned goods-receiving station and empty pallet station substantially would reduce the required resources needed to fulfill the material demand from the assembly line. The second experiment presented how well the system could handle component variety and total volume increases. In summary requires the new system fewer drivers, and resources to fulfill the demand. The introduction of an inbound inventory also makes the system more capable of handling a higher volume without occupying scarce floor space. Results from the experimental study are discussed further in section 5.3.

5.2 In-Plant Logistics System

Multiple aspects needed to be considered in the desired design choice of the in-plant logistics system, with some of them being limitations for this specific case. The limitations meant that an objectively better solution from literature maybe couldn't be considered, for instance, due to the current layout of the factory. The suggested solution of the project to implement a pull flow implies an overall more flexible system. The current system of delivering material on schedule and pushing material to local warehouses shows to be more challenging with handling an increase in the number of parts and part variety. Some of the reasons would be that it would lead to an overflow of material in the local warehouses, and the schedule would need to be re-balanced when introducing new parts. With the new suggested in-plant logistics system, the system would be more able to handle a variety of incoming materials. A demand-driven Kanban pull system shows a more even flow of material, which will keep the inventory level at each warehouse more stable, and an increase or decrease of parts will mostly only affect the fill rate of the transported trailers. When the system reaches a point where the utilization of the drivers is too low or a backlog of orders builds up, it's easier to decrease or increase the number of drivers in the system without having to re-balance the system as it is needed in the current system.

The project assumed a two-bin system would be implemented at every material delivery location. This was because it was the most efficient way of delivering material and minimizing the travel distance. Without a two-bin system, the driver must travel back and forth to a switching area to switch trailers. The assumption as mentioned before was that there would be enough space to have a two-bin system at each location, or that the delivery location could be moved to a spot with enough space.

Overall, the suggested in-plant logistics system from the project was shown to be the most beneficial within the studied material handling system, with some assumptions being made. As mentioned before, the literature could suggest some additional changes to optimize the system further, but those would be difficult to implement in this specific case.

5.3 Experimental Study

The results from the experimental study presented in section 4.3 were fairly expected, and was in line with established theories. The introduction of a new goods-receiving station, at a new location proved to be a more cost-efficient solution. The main reason is the shorter distances driven for each delivery sequence. As presented in Figure 4.6, the total utilization of the drivers is relatively level for both cases. Worth noting is that the immediate value-adding activity of delivering material is lower in the new case. This may seem as a less efficient solution, but the effect of the more central location of the new goods-receiving station means that the material has to be transported for a shorter duration to reach its destination. This is more favorable since it allows for a more responsive and lean flow of material.

Experiment 2 provided the project with a prediction of how the requirements for the system increase with an increase in volume. This is useful information regarding how the system is flexible within its capacity, and to make cost-efficient decisions regarding up- and downscaling. Worth noting is that the current amount of tugger drivers, five, is capable of handling 160% of the current volume with the introduction of a new goods-receiving and relocation of the empty pallet station. When only introducing a demand-driven pull flow, is the required number of drivers the same as today. A conclusion can then be drawn that the most important factor when designing an internal logistics system is to limit the transport distances. This will make the system more flexible towards variation and also require fewer resources.

An important function of the improved system is how well it can handle an increase in variety and volume without occupying floor space in the plant. The introduction of an inbound warehouse located at the goods-receiving station has contributed to this. Measurements of the inventory levels at the local and inbound warehouses show that the warehouse is exposed to a higher degree of variation. Figures 4.10-4.13 are clearly representing this. The difference between the maximum and minimum levels is much higher in the inbound warehouse than in the local warehouses. The increase is also much greater in the inbound warehouse with an increased capacity factor. The increase in the local warehouses is solely based on the increase in component variety. In summary, it can be said that the introduction of a demand-driven pull flow and an inbound warehouse, acting as a buffer, at the goods-receiving fulfills the requirements of handling an increase in part variety. The system manages this without occupying additional floor space in the plant.

5.4 Methodology

Different approaches could have been made if there was different delimitation's throughout the project. For instance, the project was limited to only consider the material transportation using tugger trains. If deliveries from external material suppliers would be considered, the results of the simulation model could be more nuanced. 40% of supply chain companies identified late deliveries as their biggest problem [50], and by always assuming that external material deliveries arrives at the correct times, the results miss out on that kind of disturbances. That means that it isn't possible to test if there sometimes would be missing material in the inbound warehouse and how that would affect the overall system, and if a larger safety stock would be needed.

Another aspect that could affect results of the project could be the assumptions made on the increased volume of parts. It is hard to make assumptions on how the future increased demand will be. If only the volume of the current parts are increased, it would be easier to make assumptions, but as mentioned throughout the project, the variety of parts will increase. How the variety will increase is difficult to assume, because assumptions of both the number of new parts and volume of them would have to be made.

Generative AI tools were only used throughout the project to help with tips on how to handle and format the historical material data used in the simulation model. There could however have been more potential to use this kind of technology to save time and improve the project, for instance to find better parameters for the model or optimizing them.

5.5 Sustainability

The concept of sustainability has during the later years expanded from only including environmental sustainability, to also including economic- and social sustainability in a "triple bottom line" [51]. This section will discuss how this project can contribute to sustainability within all these three areas.

The presence of waste in an operation is one of the main drivers for increased costs and environmental impact [52]. All seven types of Muda, presented in section

2.3.1, consume both monetary resources as well as physical resources. The main effects of the proposed logistics system reduce the occurrence of transportation, over-processing, and motion. Relocation of the goods-receiving station and empty pallet station reduces the unnecessary movement of drivers, pallets, and trailers. Over-processing is reduced by having a functional two-bin system that eliminates the need for unnecessary trailer switches. Motion is also eliminated with a functional two-bin system. This increases the chance for long-term economic success, as well as limiting the required resources.

One of the strengths of the utilization of a simulation model for operations evaluation and optimization is the fact that layouts and solutions can be tested and evaluated in a digital world before real-world implementation [18][20][53]. The flexibility and user-friendly characteristics of a simulation model allow for detailed analysis, to a low investment. The detailed analysis limits the risk of faulty judgments, which would lead to great losses in money and time if implemented in the real-world. A simulation study also enables concurrent engineering, meaning that current operations can continue during the development process [16]. In this case, means it that the assembly plant can produce trucks for as a long period as possible without closing down for rebuild.

The present system, which is controlled by a scheduled push system, lays a lot of responsibility on the knowledge of the driver. Special cases, with lack of instruction, need to be handled by the driver and initial perceptions of the system are that it is complicated. A standardized sequence removes the pressure from the drivers, and a digital kanban system eliminates the need to keep track of an entire day schedule, the driver only has to consider one assignment at a time. In summary, does this reduce the stress put on the workers and create a more sustainable workplace [54].

5.6 Future Work

This section describes potential future work in two different sections. The first part is regarding what future work could be done and what potential it would have for the case company, followed by potential future research from an academic perspective within this area.

5.6.1 Case Company

This project has given insights into how the future increase in variety and amount of parts could affect the logistics system and insights into how different changes in the system would handle the increase. This gives the company information that can be used for decision-making, which gives them a more solid understanding of the effects of new solutions before implementing them. Some of the solutions, such as building an additional goods-receiving station or moving the empty pallets station, would mean a high cost, and can now be easier evaluated without actually implementing them. Different solutions would also come with different costs and problems with implementation, and by having the DES model from this project, the company could prioritize and weigh the different solutions. It means that the company doesn't have to only choose the best solution in terms of the best output, but could also choose a solution that is good enough in terms of output, at the same time as it matches their priorities and fits their future strategies.

Due to time limitations, only a few concepts could be tested with DES in this project, meaning that there may be some additional concepts that the company would like to test. With the DES model created in this project, the company has a solid foundation that will save them time if they want to do additional tests. DES was also unutilized until now in the department at the company where this project took place, so by giving them the DES model from this project, they get a better understanding of what can be done with this tool.

The project has not taken a practical implementation of the suggested system into consideration. A real-world implementation requires the design, development, and implementation of a functional electronic kanban system. A software system needs to be implemented that provides drivers with information about where they are supposed to go and to what delivery location. The kanban trigger level will also have to be analyzed for every article number to achieve a smooth flow without unnecessary inventory holding.

5.6.2 Future Research

The time limitation of the project meant that only a few concepts could be tested with DES. The main concept chosen was a pull flow which was decided through literature studies. It would nevertheless be interesting to test other concepts through DES as well, to get a more reliable result of different concepts and how it could affect the system in the future. Some concepts were also discarded due to them not being possible or suitable for the specific case at the company. That was because of limitations connected with the overall layout of the factory that couldn't be changed, but also other aspects regarding how the company operates today, for instance, the production or logistics. By testing more concepts, the study could get a more nuanced result that is applicable outside the specific studied case.

The DES model created in this project is very specific for the case at the studied company and would lead to some difficulties if it were to be tested for a different case. Therefore, some future work could be done to generalize the DES model more. The logic of the model is somewhat easy to adapt for different similar logistics cases, but the 3D model is only functional for this specific case and would need a lot of work to change for a different case. With that said, if the model would be adapted to be more generalized, it would be possible to easier test different cases and different solutions which would be interesting from a research point of view.

6
Conclusion

The automotive industry is exposed to a substantial transition regarding sustainability- and customer demand. A greater range of end products will have to be produced to fulfill this demand. This increases the demand on manufacturers internal logistics systems, which will have to handle an increased number of different parts. This thesis have investigated what capabilities an internal logistics system must posses to satisfy the future demand of a more flexible and variable component flora.

In this thesis, an investigation into finding a good in-plant logistics system for handling an increased volume and variety of parts was conducted. A DES model of a material handling system using tugger trains at a case company was made. The model was used to verify and test different logistics systems. The model was used to test the implementation of a pull flow, chosen through literature studies, and the implementation of different system layouts. The model also included different parameters and solutions for tests, such as different locations for inbound material deliveries and empty pallet handling location. The model also consisted of parameters to change the number of drivers etc., which could be used to optimize the system.

The main aim of the research questions was as mentioned to choose and test a suitable in-plant logistics system that can handle a future increase of parts and parts variety. This is relevant due to the future plans to introduce new truck models with an increased variety of alternative drivelines, such as electric or gas to fulfill the sustainability demands. Results show that by introducing the chosen pull flow and a two-bin system at every material delivery location within the factory would lead to a more even flow in the factory. Inventory levels at both the local warehouses, as well as the inbound warehouse, were at a steady level. An increase of parts and parts variety showed to be easy to handle without having to change the system additionally, except for changing some aspects such as the number of drivers. The big increase in overall efficiency came from introducing an additional centralized inbound material handling location, as well as moving the empty pallets handling location to a more central position. Studies also show that with the suggested in-plant logistics system, the system will be easier to rebalance after changes, which will save time and resources in the future. The improved system would also reduce the amount of waste present in the current system, and create a less demanding work environment.

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A

Conceptual Model

Project Goals

Overview: The specific interest of the investigation is to analyze how the material is transported into the Volvo Tuve factory with trainsets. Several aspects will be analyzed to create a more flexible and efficient methodology. The main focus point is the relocation of the (or establishing an additional) goods receiving. The investigation will also develop and analyze the effects of implementing a pull system instead of the current push system.

The performance will be measured in the ability to fulfill the demand for material from the production line while minimizing the required resources. Measurements used to identify waste will be fill rate and time driven with different loads.

Reasons for Improvements: The current methodology has several improvement areas and problems. The ones concerned in this project are the following.

- Currently utilizes space inside the factory (Space is limited and demanded by other processes)
- Material is pushed from goods receiving to local storages.
- Silo mentality, “as long as I am minding my own business it will work out”.
- Long driving distances
- Locked/inflexible – small changes and rebalancing are difficult for the trainsets.

Parameters: The investigations involve several parameters

- Number of Drivers: Amount of required trainset tuggers needed to satisfy the demand. Wants to be minimized.
- Number of Trailers: The number of trailers connected for the driver to pull. In the range between 1-3.
- Location GM: The location of the goods receiving station.
- Location TG: The location of the empty pallet station.
- Order rate: Test future expansions with increased material demand.
- Batch Control: Wait time for how long an order should wait for other orders until it is delivered.
- Re-Order Point: At which inventory level an order for more material should be placed.

Experimentation: Time units are expressed in minutes and the observation interval starts at t = 0. (00:00). Breaks will have to be considered in the experimentation. Experimentation consists of varying methods and different variables, leading to a selection of different cases.

Output:

- Delivery Rate: To what extent does the system satisfy the demand of the delivery stations?
- Backlog of orders
- Inventory level in warehouses
- Inbound inventory capacity

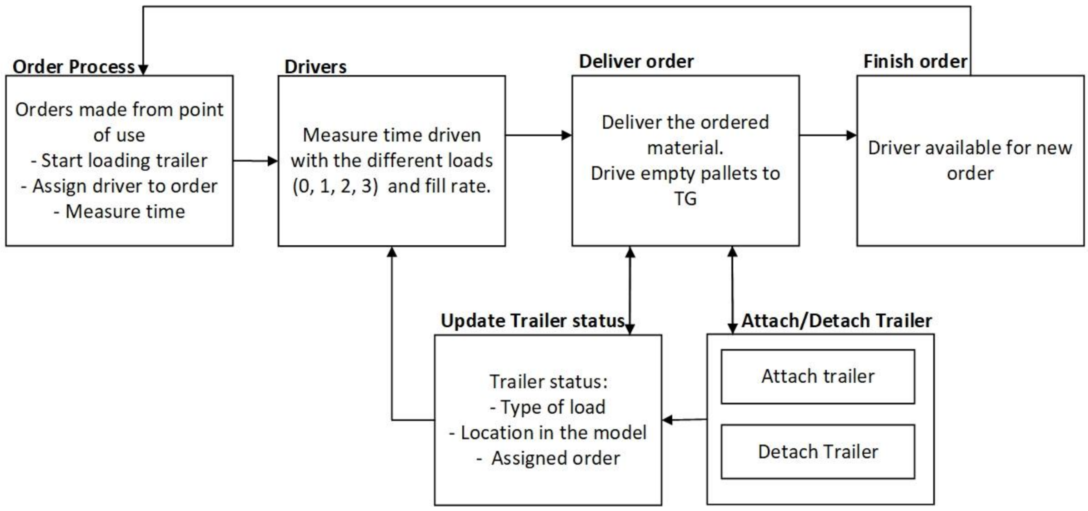
- Fill rate
- Time driven with each point: How long time the tuggers drive depending on what load and fill rate they have.

Input:

- Speed of the tuggers at different areas within the simulation.
- Demand in the factory (also a parameter).
    - Delivery rate to GM.
    - Components classification.
        - Measured in pallets.
- Delivery points for trainset.
- Max load trailers.
    - Capacity: height, weight.
- Distances/Layout (parameter for some locations).
- Empty pallets handling
    - Times, amount, location, etc.
- Loading/unloading times.
- Breaks.

Conceptual Model

Simulation framework:



Model Content

Concepts	Description	Assumptions in the Simulation
Order to Goods Receiving		
Order from Point of Use	Material is demanded from the point of use (Kanban). If material is not available in local storage, it is requested from GM. Follows the theory of JIT.	How often orders are made and how much material (pallets) is ordered. Assumption: the order is made in time, so the "normal" delivery time won't lead to material shortage. Delivery failure is measured in the time that the order is loaded in goods receiving and waiting for a driver to pick up the trailer(s). Total time from order, to order delivery should be measured. (Lead time from truck to trailer, and delivery point to point of use is not considered in this simulation)
Order Size/Amount		
Pallet	One pallet of material is requested when needed. The pallet is loaded to a trailer. More pallets can be loaded to the trailer when requested during a specific set time. This time can be altered depending on the delivery point. The time can be optimized with the simulation.	Request based on demand data. A timer is started when the first pallet is loaded. When a set time is reached is a Driver called to drive the trailer. The filling rate is measured when the driver has collected the trailer.
Trailer	Order is made as one delivery from delivery point, with a certain number of pallets. When those pallets are loaded on the trailer(s), the trailer(s) are delivered.	Same logic as "Pallet", but the minimum fill rate of the trailer is set as a parameter instead of a set time.
Buffers in GM or/and at the Delivery Point		
GM Buffer	GM has a buffer between delivery trucks and trainsets. Pallets are unloaded to this buffer and are loaded to trailers on request from the point of use.	Assumption: What time it take to load a set amount of pallets to trailers. The capacity of forklifts in GM is assumed to always be enough.
Delivery point Buffer	Buffer at the delivery point. Can either be on the delivered trailer(s), or at a local warehouse.	

Unloading Trailer Delivery point		
Unloading immediately	All pallets get unloaded as soon as possible and get delivered to the local warehouse or point of use.	The time it takes to unload depends on the number of pallets
Use trainsets as a buffer	Pallets can stay on the trailer until needed. Works as a buffer to the point of use or warehouse.	Time depends on the number of pallets and the time until the pallet is needed.
Live-unloading	The driver of the trainset waits at the delivery point during a forklift unloads the trailer before it leaves. Empty pallets is either loaded before the driver leaves or is handled by another driver/sequence.	A delay/process time for the time required to unload (and load). If another sequence is handling the empty pallets must a new sequence be implemented for emptying of these.
Loading Trailer GM		
Load Time of Trailer	The time to load is based on available data. The calculation is based on the time required for each pallet.	Time depends on the number of pallets (Data on this exists). Capacity depends on number of trailers (1-3). Assumption: The capacity of the forklifts at GM is assumed to always be enough. The height of loaded pallets needs to be considered.
The Division Between the Two Different GM's		
Delivery point connected to which GM	Every delivery/order point should relate to one GM.	Which delivery point relates to which GM? Should it depend on positioning or the supplier?
Volume for each GM	Data for volumes for each GM. Analysis if the proportion changes in the future.	Number of orders for each delivery point. Parameter for how often each delivery point is requesting material.
Drivers connected to a certain GM	For instance, 2 drivers are doing all orders for one GM, and the others for the second GM.	Simulation test. Assign drivers to specific delivery points.
Unloading Trailer Local Warehouse		
Unload Time of Trailer	Use data to measure unload time/pallet and transport time from trailer to point of use/local warehouse	Process time/delay based on fill rate (nr of pallets) of the trailer.
Loading of Empty Pallets		
Load time of empty pallets to Trailer	How long does it take to collect and load an empty pallet to a trailer.	Delay/process time that is deciding the filling rate of the trailer.

	Flow out is the same as flow in. But the time is different.	
	Capacity needed for empty pallets	
2 Bin System		
1 Trainset	The current solution. 2 spaces for trainsets, and 1 trainset is stationed at one of those spaces. Delivery is done by switching the set, from a full to one with empty pallets. Material must be unloaded before empty pallets can be loaded. Material can be delivered right away without removing empty pallets. This solution will initially be evaluated	Status for each trailer is changed when it is unloaded/loaded. The first step in the sequence of delivering material is to collect material at GM and deliver it to the delivery point.
2 Trainsets	The standard in VOC. 2 spaces that always has material. When one trailer is emptied, it is filled with empty pallets. Empty pallets has to be transported away to TG before new material can be delivered. Requires more space and trailers functions as a buffer.	Sequence is started by transporting empty pallets to TG before collecting material and delivering it to the delivery point.
Empty Pallets location (TG)		
Placement for the empty pallets delivery	The time/distance to TG should be minimized.	Parameter: Distance to TG. Assumptions: How much space is needed? Different costs and competition for different locations. Capacity at TG, number of trailers needed in the system.
	Locations for TG pickups. If they are needed and how many should it be for higher efficiency?	
Breaks, Lunch and End of Day		
Request close to end of session	A new delivery can not be started close to a break or end of day.	Compare the standard time of an order task to how long it is until the next break. If time is not available, save the order task to after the break and check next break.

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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