IMPROVING THE INTERNAL BIG VOLUME TRANSPORT LOGISTICS AT BOSCH THERMOTECHNIEK DEVENTER

Master Thesis – Thom Oldemaat

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Master Thesis

Improving the Internal Big Volume Transport Logistics at Bosch Thermotechniek Deventer

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Preface

Dear reader,

With pleasure I present to you my Master Thesis 'Improving the Internal Big Volume Transport Logistics at Bosch Thermotechniek Deventer' that I have written during the final phase of the Master's study Industrial Engineering and Management at the University of Twente. After a very interesting period at Bosch Thermotechniek, I can look back on a pleasant time in which I learned a lot.

I want to thank my supervisors Peter Schuur and Martijn Mes for providing me with constructive feedback whenever this was needed. This contributed a lot to the quality of the thesis project. I also want to thank Berry Gerrits for all his feedback, as he provided me with clear insights on how to tackle problems during the construction of the simulation model. Besides that, Berry also helped to guide me in the right direction for both the simulation model as the thesis report.

I am also grateful to the people at Bosch who supported me during the graduation project. In particular, I want to express my gratitude to Mathijs Piron. Mathijs, being my company supervisor, continuously guided me along the way to the completion of this Master Thesis. Finding the right information in such a big company can sometimes be a real challenge, but I could always discuss any issues regarding the progress of the thesis project with Mathijs.

Finally I would like to thank my university colleagues. During the last years, I had a great time working on several projects with Carly, Niek, and Sébastiaan, and during the thesis project I had many constructive peer review sessions with Ieke. It was pleasant to work with all of you!

For me, all that remains is to wish you a pleasant read.

Thom Oldemaat
April, 2019

Management Summary

This Master Thesis is about improving the internal big volume transport logistics from the warehouse to the production area at Bosch Thermotechniek Deventer.

Bosch Thermotechniek Deventer is part of the thermotechnology division of the global Bosch concern. The thermotechnology division of Bosch is leading in the heating and hot water industry. The production plant in Deventer assembles central heating boilers that are used in the residential market. Replenishing the materials for the assembly process is done by milkruns and forklifts. Milkruns deliver Small Volume (SV) materials and the forklifts deliver Big Volume (BV) materials. The SV materials are crates and small boxes that can be manually handled by an employee. The BV materials are placed on pallets, which are larger and much heavier. This thesis focusses on replacing the forklifts for the BV material supply and the thesis proposes improvements for this process. A preliminary study is performed to analyse which options are suitable within the production plant for replacing the forklifts. The research question that is in line with the focus of this thesis, is the following:

“How should the logistic system for the big volume processes be designed to efficiently replace the forklifts in the production environment at Bosch Thermotechniek Deventer? Specifically, which option will be more efficient; a milkrun system or an automated guided vehicle system?”

To give an answer to this research question, the research is divided in several phases. At first, the current situation is analysed. The performance of the current situation is determined by simulating the process in Siemens Plant Simulation. Next, literature is used to find suitable solution methods for implementing an Automated Guided Vehicle (AGV) system or a milkrun system. The information obtained and the information on limitations of the production plant itself, are used to come up with proposed future situations. These proposed future situations are simulated and compared with the current situation.

In the current BV logistics, a Kanban card is placed in a collection box by a production worker when a pallet with material is empty. The production worker removes the packaging material and the empty pallet is placed on a dedicated stack close to the production line. The removal of these stacks is a separate process, performed by one employee. After the Kanban card is placed in the collection box, a SV milkrun driver takes them out during his milkrun round and scans the cards. Two forklift drivers are responsible for the supply of BV materials. These two drivers both pick a single pallet with materials and directly transport the pallet to the location in the production area. The picking of materials is done by a first come first served principle, based on the orders that are scanned by the SV milkrun driver. When there are more than seven orders waiting to be picked, a third forklift driver is deployed who only picks materials. In that case, the other two forklift drivers only transport the materials. When there are no waiting orders left, the process switches back to the situation with two drivers.

As Bosch did not know the performance of the current situation, this situation is simulated in an extensive discrete event simulation model in Siemens Plant Simulation. The performance is measured according to the production planning of 2018. The simulation model shows that the average replenishment time of the orders is 17.6 minutes, with a service level of 99.957%. The yearly process costs are *(confidential)*. Every percentage of reduction in the service level results in *(confidential)* of extra yearly costs of the process. This is discussed with the stakeholders and a threshold is set for the service level of future situations. The threshold of the service level of these situations is set to 99%.

Literature is used to come up with possible solution methods for replacing the forklifts by an AGV or milkrun system. Different types of AGV and milkrun systems are found and for the BV process itself, different strategies are found. The strategies concern the organization of the BV logistics itself and the traffic directions that should be implemented for safety during transport. The different transporting vehicles and the different options for the process are analysed for applicability in the production plant. Next, the solution methods that are suitable in the production plant are simulated in Siemens Plant Simulation, by adjusting the model that is used in the current situation.

Two simulation models are made for the future situations. One simulation model is used for a simulation study with the BV AGV system and one model is used for a study with the BV milkrun system. In both simulation models, the picking process is changed to having a dedicated picker in the warehouse. For the AGV system, the shortest route according to the traffic rules is used through the production area. For the milkrun system, an efficient route is calculated and implemented in the simulation model and the return of packaging material and empty pallets is included in the process. The required capacity is determined for the AGVs and for the milkrun configurations, and adjustments are made to perform each experiment with a different combination of process strategies. These strategies are prioritizing the orders in the warehouse, using a time schedule for delivering materials, and performing a full route through the production area or not.

Table 1 shows the results of every simulation study. The results in the first row concern the current situation as described on the previous page. The rows concerning the studies of the AGV and milkrun system contain results of the experiments that have a service level above the threshold of 99% in combination with the lowest yearly costs. For the milkrun study, the results come from the following experiment: 2 milkrun trains that both carry up to 3 materials at a time. The orders are prioritized and the milkruns drive according to a time schedule and go back to the warehouse if the milkrun has delivered the last material, instead of performing the full route through the production area. For the AGV study, the results come from the experiment with 2 AGVs that both perform the shortest route through the production area according to the traffic rules. For the AGV system, orders are also prioritized in the warehouse.

<table>
<tr><th>Simulation study</th><th>Avg. replenish time [min]</th><th>Total number of orders</th><th>Orders within replenish time</th><th>Orders too late per year</th><th>Yearly costs of process</th><th>Investment costs</th><th>Production loss per year</th><th>Service level</th></tr>
<tr><td>Current Situation - Future Traffic Rules</td><td>17.6</td><td colspan="6" rowspan="3">Confidential</td><td>99.957%</td></tr>
<tr><td>Future Situation - Milkruns</td><td>20.0</td><td>99.997%</td></tr>
<tr><td>Future Situation - AGVs</td><td>13.6</td><td>100.000%</td></tr>
</table>

Table 1: Results of the Simulation Studies

When looking at the table, implementing the milkrun system costs approximately *(confidential)* extra per year, compared to the current situation. Therefore, the milkrun process is not profitable as money that is invested will not be earned back. The AGV system has the lowest yearly costs, which is approximately *(confidential)* cheaper than the current situation and *(confidential)* cheaper than the milkrun system. Including the investment, the return on investment is slightly under six years. The ergonomic advantage of the milkruns does not compensate the yearly costs difference of *(confidential)* compared to the AGV system. Therefore, the AGV system is the most efficient for replacing the forklifts. The average replenishment time is 13.6 minutes with a service level of 100%.

Two AGVs are needed and orders have to be prioritized in the warehouse. In order to let this process work, the orders that have priority should get a special mark on the Kanban card, such that the picker knows what orders to pick first. Furthermore, the current locations of the BV materials in the production lines have to be changed. Every pallet location needs a pallet rack under which the AGV can drive to deliver the material. The current pallet racks and roller tracks need to be removed and replaced, such that every location has that specific pallet rack.

Finally, Bosch is recommended to:

- Look into the possibilities to reduce the investment of the AGV system;
- Do research on scanning Kanban cards by production workers;
- Perform a thorough analysis on including the return of packaging material and empty pallets in the process.

The roadmap in Table 2 shows the priority of the recommendations, the responsible department that needs to perform the analysis, and the actions to take during the analysis. The recommendations are sorted from quick analysis on the short term to extensive further research.

Priority	**Responsible department**	**Action(s) to take**
Reduction of the AGV system investment	The logistic department	Understand what requirements are needed for the pallet racks Analyse what alternative parties can manufacture the pallet racks
Kanban cards are scanned by the production workers	The production department The logistic department	The production department: Analyse the impact on tact times of production lines The logistic department: Analyse what possibilities exist for facilitating the scanning of Kanban cards
Including the return of packaging material and empty pallets	The logistic department	Analyse the capacity required due to process changes when this is included in the BV logistcs

Table 2: Roadmap of the Recommendations

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Lists

This report is written in such a way that it is a clear report and that everyone can understand it, insofar possible. However, some phrasing needs some educational background or affinity with the subject. To make these phrases more understandable, a list of abbreviations is composed. Besides this list, two other lists are composed: the list of figures and the list of tables. These two lists provide an overview with the position of the figures and tables used in this report.

List of Abbreviations

AGV	Automated guided vehicle *Vehicles that can drive independently through the production plant.*	Page: 5
AS/RS	Automated storage/retrieval system *Automated system that picks a material and brings it to the picker or store a material in the warehouse.*	Page: 33
BV	Big volume *Materials that are transported on pallets.*	Page: 3
CH-boilers	Central heating boilers *The finished products which are produced in the production plant.*	Page: 1
CI	Confidence interval *A range of values in which a certain parameter is expected to lie, with a specified probability.*	Page: 27
CPP	Chinese postman problem *A mathematical problem of graph theory that is used to find the shortest route through a closed circuit of paths, taking in account that all paths are travelled at least once.*	Page: 32
CRN	Common random number *The use of random number streams that makes sure the same random numbers can be used for a certain operation in different configurations and experiments.*	Page: 27
DES	Discrete event simulation *A codified model that represents the reality and that can be used for analysing purposes.*	Page: 8
FCFS	First come first served *A principle that is used to handle big volume materials that are transported to the production area.*	Page: 20
FG	Finished goods *The finished central heating boilers that are transported on pallets.*	Page: 3
KPI	Key performance indicator *Measure for the overall performance of the simulation models.*	Page: 14

LOG	Logistic department *A department within Bosch Thermotechniek Deventer which is divided into four sub departments.*	Page: 3
PERT	Program evaluation and review technique *A technique which determines the distribution for the duration of an operation.*	Page: 20
ROI	Return on investment *The period in which the investment is earned back.*	Page: 3
SV	Small volume *Materials that are transported in crates.*	Page: 3

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Chapter 1 – Introduction

In the framework of completing the Master's study Industrial Engineering and Management at the University of Twente, this research is performed on improving the internal big volume transport logistics at Bosch Thermotechniek Deventer, located in The Netherlands.

Bosch was founded by Robert Bosch in 1886. The company was known for its innovative strength and social commitment. Through the years, Bosch expanded to the globally operating company as it is known today (Bosch Global (a), 2018). It has around 440 subsidiaries and regional companies, which are located in approximately 60 different countries. These companies develop innovative products and services for the mobility sector, for at home, for the industry and trades sector and for market-specific solutions. Worldwide, Bosch has over 400,000 employees (Bosch Global (b), 2018).

At first, Section 1.1 introduces Bosch Thermotechnology. The brands and markets are explained briefly, together with an explanation of Bosch Thermotechniek Deventer. Next in Section 1.2, the core problem and the problem context are described, since these aspects provide a basis for the research. After the problem is clear, the focus of the research is described in Section 1.3. This focus is explained by describing the research goal and scope, together with the research question. Section 1.4 describes the methods and data collection techniques which will be used. Finally, the rough thesis outline is discussed in Section 1.5.

1.1 Introduction of Bosch Thermotechnology

The thermotechnology division of Bosch provides solutions for the 'Residential' and 'Commercial and Industrial' sectors. For different markets, different brands are used. The brand Bosch is used for the 'Commercial and Industrial' sector, while the 'Residential' sector has different brand names for different countries. For the Dutch market, Nefit is the brand of products that are used at homes (Bosch Thermotechnology, 2018).

Nefit has several types of products like Central Heating boilers (CH-boilers), heat pumps, hot water boilers, and so on. A CH-boiler is a system used to warm buildings by heating water. The water flows through a network of pipes and radiators, which provides heat for the building. The power of a CH-boilers is expressed in kW, which is the thermal power output of the unit for heating the building. To compare the power range of the products with those of the brand Bosch; the CH-boilers of Nefit have a power range varying from 25 kW to 50 kW, which is enough for warming houses. These CH-boilers can be connected to each other to create a more powerful modular system if required (Nefit (a), 2018).

Bosch has a lot of different products like CH-boilers, heat pumps, combined heat and power units, air conditioning systems, and so on. The Bosch CH-boilers have a power range from 650 kW to 38,000 kW. These CH-boilers can also be connected together when more power is needed, for example in large production plants (Bosch Industrial, 2018).

1.1.1 Bosch Thermotechniek Deventer

Nefit, known as the producer of CH-boilers in The Netherlands, is part of the Bosch Thermotechnology division since 2004. Now, over 700 employees work at the Deventer location (Nefit (b), 2018). Bosch Thermotechniek Deventer facilitates a research and development department, a department for production, and a logistics department. Besides this, there is a sales department for both the brands Nefit and Bosch (Bosch Thermotechniek Deventer, 2018).

The production plant in Deventer is dedicated to manufacturing CH-boilers for the brands Bosch, Buderus, Junkers, and Nefit. Nefit is produced for the Dutch customers and the other brands are produced for the international customers, with Germany as the main market. To be able to keep a good customer satisfaction, continuous improvement is necessary. By constant innovation, the production plant can stay competitive to other production plants in low-wage countries. Due to this, efficiency has a high priority.

Figure 1 shows the layout of the production environment of the plant. The following CH-boiler families are produced at this production plant, each on a dedicated production line (Nefit (c), 2018):

- 9000i: these mid-range models are the most quiet and economical. These models are produced on the DNA production line.
- ProLine Nxt: these low-cost models are the smallest with smart settings. Production of these models is performed on the ProLine Nxt production line.
- TrendLine: these mid-range models are very efficient and provide an optimal balance between comfort and energy saving. The models are produced on two production lines: TLA and TLB.
- TopLine: these top-end models are suitable for connected systems and different types of gas and are produced on the B3U production line.

Of course, the products produced at this plant are continuously developing and improving through the years, but these product families and production lines are the basis of this plant.

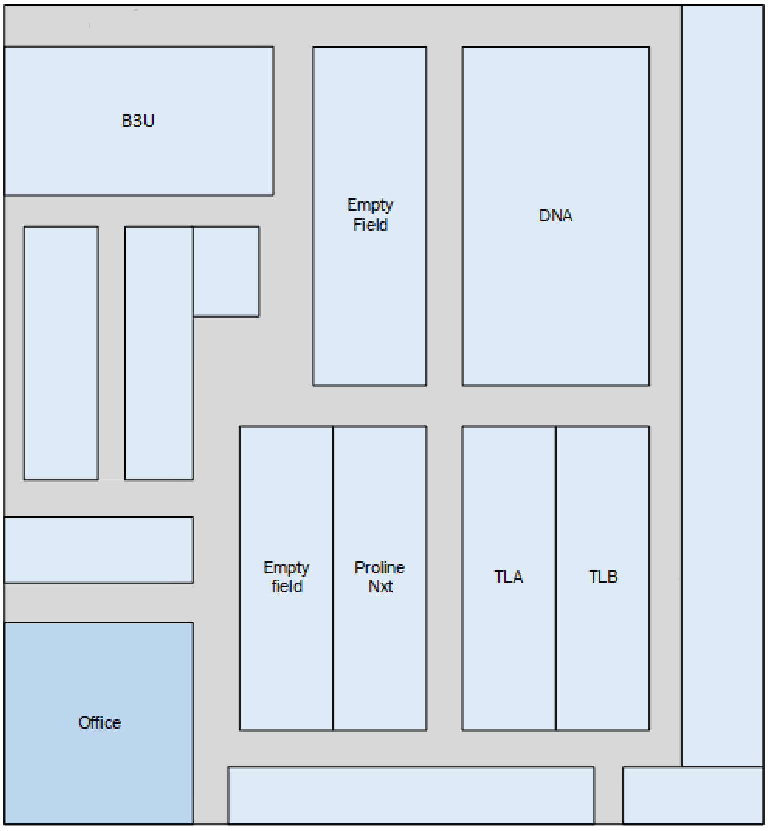

Figure 1: Layout of the Production Environment

1.1.2 Internal Logistics in Deventer

The logistic department (LOG) is responsible for all movements of material, from incoming material to delivering Finished Goods (FG) to the customer. LOG is divided into four sub departments. Each sub department is responsible for a certain part of the logistics in the production plant. The four sub departments are the following:

- LOG-1: Contact with the customer and creating a production plan according to the sales plan.
- LOG-2: Controlling and managing the incoming materials for all production processes.
- LOG-3: Controlling and managing all internal logistics.
- LOG-4: Process improvement on project basis and supporting the other sub departments.

The internal logistics for replenishing materials to the production lines, are divided into Small Volume (SV) and Big Volume (BV) transportation. The SV materials are crates and small boxes, which one can carry. The BV materials are placed on pallets, which are larger and much heavier.

The SV supply to the production lines is done by an SV milkrun, which is a trolley that follows a fixed route. The BV supply is done by forklifts that deliver big volume materials on pallets to different locations in the production lines. On average *(confidential)* pallets with BV materials are transported by forklifts every day, with peaks in the workload up to *(confidential)* pallets. Besides that, the packaging material of the BV materials that have to be removed, are also transported by forklifts.

1.2 Introduction of the Core Problem

Bosch has a vision for all the plants worldwide to have a production environment without the use of forklifts. This is desired in order to ensure more safety for employees and to ensure less damaged materials and products. Therefore, Bosch Thermotechniek Deventer needs to perform a research on the implementation of a good alternative. While doing so, it is important to take efficiency, the initial investment, and the Return on Investment (ROI) into account as these are important factors.

1.2.1 Problem Context

Bosch Thermotechniek Deventer has several reasons to eliminate forklifts from the production environment. At first, the global decision of Bosch for more safety is an important factor. After having some discussions with production managers and logistic managers, the following four reasons turned out to be of importance as well:

- Good forklift drivers are hard to find, because of the market conditions. Several forklift drivers are only needed during the busiest periods and work on a flexible schedule or even only work when called upon. Therefore, flexible forklift drivers who can also work elsewhere for better circumstances will leave this company.
- Bosch stands for innovation and also wants to showcase this image to their customers. A production environment without forklifts for the logistics contributes to this image, since customers who visit the plant get a more innovative impression about the whole company.
- Bosch wants smart factories with the implementation of Industry 4.0, which is a concept of automation and data exchange in factories for improvements. Industry 4.0 is desired, to make controlling and optimization possible in more processes. The ultimate goal of Industry 4.0 is to make the Bosch factories more efficient and more flexible.

1.2.2 Alternative Options

A research is done about the different options for material transport equipment in a factory. Material transport equipment are divided into three categories (Tompkins, White, Bozer, & Tanchoco, 2010):

- Conveyors;
- Industrial vehicles;
- Monorails, hoists, and cranes.

Conveyers

There are a lot of different conveyor-types. According to Tompkins et al. (2010), conveyors are used when materials have to be frequently moved between specific points. Hence, there must exist a sufficient volume of movement to make a conveyor system an interesting investment (Tompkins, White, Bozer, & Tanchoco, 2010).

At Bosch, the current production environment has no conveyers. Therefore, the production lines are not equipped for this type of transport at the moment. Besides that, the number of movements to a specific point is not high, since for example the average *(confidential)* pallets of BV materials per day are transported to more than 50 locations. Because of these reasons, the investment would be enormous.

Monorails, Hoists, and Cranes

Tompkins et al. (2010) also describe that monorails and cranes are generally used to transfer materials in the same general area. Hoists are used for monorails and cranes to facilitate the positioning, lifting, and transferring of materials within a small area. The flexibility of monorails, hoists, and cranes is higher than the flexibility conveyors provide, but they do not have the flexibility provided by variable-path industrial vehicles (Tompkins, White, Bozer, & Tanchoco, 2010).

At Bosch, the materials are transported to different areas through a hallway. The products also have widely varying locations in de production environment. Therefore, the transporting units need to be flexible and capable of going to the different areas. This means that monorails, hoists, and cranes are not capable of transporting the pallets in the production plant of Bosch.

Industrial Vehicles

According to Tompkins et al. (2010), industrial vehicles are versatile in performing material handling. They are also described as variable-path equipment. Industrial vehicles are generally used when the movements are either intermittent or over long distances, or when the primary function is manoeuvring or transporting. The industrial vehicles are divided into three categories: walking industrial vehicles, riding industrial vehicles, and automated industrial vehicles. Each category has several options (Tompkins, White, Bozer, & Tanchoco, 2010).

Walking Industrial Vehicles

- Hand truck and hand cart: used for small loads and short distances.
- Pallet jack: used to lift, manoeuvre, and transport a pallet load of material over a short distance. The lifting capability is typically from six to ten inches.
- Platform trucks: used for short distances, no lifting capability, and a platform instead of forks.
- Walkie stacker: extends the lifting capability of a pallet jack and is used for short distances.

Riding Industrial Vehicles

- Pallet truck: extends the transporting capability of the pallet jack, allowing the operator either to ride or walk. Used when the distance can sometimes be too much for walking.
- Tractor trailer: extends the transporting capability of the hand truck by a powered, rider-type vehicle to pull a train of connected trailers. It tows the connected trailers.
- Counterbalanced lift truck: extends the transporting and lifting capability of the pallet jack.
- Straddle carrier: carries the load underneath the driver. Used outdoors for long, bulky loads.
- Mobile yard crane: heavy machines that are used outdoor for heavy loads.

Automated Industrial Vehicles

- Automated Guided Vehicles (AGVs): these vehicles are driverless industrial trucks. A vehicle which follows a predefined path along aisles. It can be designed to operate as a tractor, pulling one or more carts, or as a unit load carrier. Unit load AGVs are the most common type in manufacturing and distribution. The path can be a simple loop or complex network and there may be many pick and place locations along the path.
- Automated electrified monorails: this is a self-powered monorails. The moving units move along an overhead monorail, but instead of being driven by a chain, it has an electric motor.
- Sorting transfer vehicles: these vehicles can automatically load and unload large and small unit loads at pickup and deposit points, located around a fixed path on for example rails. It is a high-throughput unit load-handling system.

At Bosch, forklifts are used for transporting the BV materials, which are counterbalanced lift trucks from the category riding industrial vehicles. Because of this, walking industrial vehicles are not an option for the BV logistics, as this is a step down in flexibility, ergonomics, and innovation. The same holds for the pallet truck. Alternative options for the counterbalanced lift trucks are tractor trailers or AGVs. The other types from the categories riding or automated industrial vehicles are not an option, since these are meant for outdoor processes or they need a complete railway system through the production plant besides the transporting units themselves.

To cope with the elimination of forklifts, two alternatives will be considered. The first alternative is a tractor trailer system (at Bosch called: milkrun system), because this system has proven to be an efficient way of replenishment as it is already implemented for the SV materials. The second alternative is an AGV system, because AGVs have shown to be an innovative solution for logistical problems. For both options, it is important to know how this could be implemented, which possibilities there are, and what the consequences are.

1.2.3 Problem Statement

An alternative for the existing BV supply should be implemented, as Bosch Thermotechniek Deventer wants to eliminate the forklifts which are used for this logistics in the production environment. The transportation of packaging material and empty pallets are also done by forklifts. Therefore, the alternative will also include these logistics.

Alternatives which will be examined are a milkrun system and an AGV system. It is obvious that the changes in the logistics have a direct impact on the production lines, since the way of picking and placing changes when another type of transportation is used. Therefore, there is a need to research and implement a suitable logistic solution that also considers the needs of the production department.

1.3 Research Objective and Research Questions

At first, the research objective with the research scope is described. This makes clear what will be delivered and which aspects will be covered. With the objective and scope, the research question and sub questions are determined.

1.3.1 Research Objective and Scope

The research objective is to provide Bosch Thermotechniek Deventer with a plan on how to improve the logistics of the BV replenishment and packaging material removal in order to be able to eliminate forklifts in the production environment. The solution is required to keep the performance of the replenishment time the same as it is in the current situation. Besides this, the solution is desired to have an ROI period of two years.

The project is limited to examining two alternatives: a milkrun system and an AGV system. These alternatives are compared to each other and to the current situation. The project concerns the BV logistics, which means that changing the SV logistics will not be part of the analysis. The SV logistics is therefore a constant factor in the analysis, since this is traffic on the same paths as the BV process.

The replenishment of the production lines in the analysis covers the logistics from the warehouse to the production lines. Therefore, the way of storing also is relevant during this project. The transport from external suppliers to storing the parts in the warehouse will be left out of the analysis. The production lines will also not be changed. Only the design of the pick and place locations within a production line can be changed to make a logistic system accommodate the production lines.

1.3.2 Research Question and Sub Questions

Based on the problem statement, the research objective, and the scope of the research, the following research question is to be answered during this thesis project:

"How should the logistic system for the big volume processes be designed to efficiently replace the forklifts in the production environment at Bosch Thermotechniek Deventer? Specifically, which option will be more efficient; a milkrun system or an automated guided vehicle system?"

To get an answer to the research question, the project is divided into the phases shown in Figure 2.

Figure 2: Project Phases

The research question is divided into sub questions. The sub questions are structured by the phases of the project. Therefore, answers found in certain phases, can be used during the next steps. The methods used for the sub questions are described in the next section. The following sub questions are required to get an answer to the research question:

Current Situation

1. *How is the current process flow arranged?*
2. *Which safety regulations are used in the current process?*
3. *What KPIs are currently in place, concerning the internal big volume logistics?*

Current Performance

4 What is the performance of executing big volume orders, in terms of lead times?

Literature Review

5 Which (safety) regulations should be used for all traffic in production?

6 Which methods can be used to implement milkruns or AGVs in logistics?

7 Which pick and place options exist when using a milkrun or AGV system?

8 How can the control of a milkrun or AGV system be organized?

Improvement Analysis

9 What are the technical requirements for the milkrun process and for the AGV process?

10 What is an efficient route design for a milkrun process and for an AGV system?

11 What capacity is required in the new process, by taking into account fluctuations in demand?

12 Which logistic system should be used, in terms of the performance and the ROI?

Implementation of Improvement

13 How should the system be implemented?

1.4 Methodology and Data Collection Techniques

The methods and data collection techniques used, are different for each phase of the project. In Section 1.4.1, the methods used in every phase are described. Section 1.4.2 discusses the simulation model and why it is needed.

1.4.1 Methods and Data Collection per Phase

Each phase needs a different approach, concerning the methods and data collection techniques used.

Current Situation

The questions concerning the current situation are answered by monitoring the process and having interviews with several employees.

Current Performance

The performance of the current situation is calculated by simulating the process in a simulation model. Therefore, data is analysed and interviews are held to get reliable parameters. The need for simulation is explained below. The answers to the questions in this phase are used to compare results of the improvement analysis.

Literature Review

A literature review is done to get information about different options for the logistics, especially information about using a milkrun or AGV system. This information will help to realistically make calculations for the improvement analysis.

Improvement Analysis

During the improvement analysis different systems are simulated, which will provide a clear view on what is needed and how this will affect the performance. The answers to the questions in this phase make it possible to compare the two options for the new situation with the current situation.

Implementation of Improvement
A choice is made about which alternative system to use. With all the information gathered, the questions concerning the implementation can be answered and a recommendation can be written.

1.4.2 Simulation Model

Discrete Event Simulation (DES) is analysing a complex system by codifying its behaviour as a sequence of well-defined events (Rouse, 2012). DES models are powerful models when various settings need to be considered in order to find efficient configurations, especially when the system considered has dynamic and stochastic properties (Nilsson, 2001). A system has stochastic properties if there are consecutive events with random outcomes.

Such a DES model is executed, because various settings will be analysed and because the internal BV logistics has dynamic and stochastic properties. In the system, different transporting units use the same paths and drive along routes on which overtaking often is not possible. Therefore, unpredictable events as waiting and traffic congestion can occur at varying places which result in dynamic and stochastic properties.

During the improvement analysis phase, at first a calculation on the logistic part will be executed. The routes and the pick and place locations will be simulated to calculate the number of transporting units needed. At this stage, the pick and place locations have each a certain processing time, which represents the complete operation. Next, with the outcomes of the DES model, the design of the pick and place locations will be determined.

The simulation model will be validated externally by keeping track on variables that can be checked by observations in the current process.

1.5 Deliverables

At the end of this project, the following items will be delivered:

- The DES model.
- The new design of the logistics, which includes the following:
  - Type of transporting units;
  - Logistic routes;
  - Design of the pick and place locations.
- The thesis report in which the steps of the research are described with clear argumentations.

1.6 Thesis Outline

The structure of the thesis is in line with the different phases of the project which all have their own sub questions and deliverables.

Chapter 1: Introduction
The introduction of the company, the core problem, and the scope and structure of the project are described together with the rough outline of the project.

Chapter 2: Current Situation
An analysis is done about the current process. This analysis covers the characteristics and activities of the process.

Chapter 3: Current Performance
The current process is further analysed to get information about the performance, limitations, and occurring problems. The performance will be measured, using the simulation model.

Chapter 4: Literature Review
A literature review is used to get information on possible solutions for different aspects of logistics. These solutions will be used in the improvement analysis.

Chapter 5: Improvement Analysis
The improvement analysis describes how the simulation model is used. The model and the calculations form the basis of the recommendation for the solution that needs to be implemented.

Chapter 6: Discussion of the Analyses
The discussion provides the opportunity to recall what is done and why it is done. As the overall objective is a complex question, this explanation provides the baseline for the proposed way of implementation.

Chapter 7: Implementation of Improvement
The implementation phase describes how the chosen solution can be implemented.

Chapter 8: Conclusions and Recommendations
The main conclusions of the project and recommendations for future research explain how further steps for implementation and monitoring should be arranged.

Chapter 2 – Current Situation

The current situation is analysed in chronological order. The process starts when a production worker has used the last article of a material, so it has to be replenished. Next, an order is printed at the warehouse such that the forklift driver knows which article to pick and where to place it. Now, the driver picks, transports, and finally delivers the article at the location in the production line. The pallets and the packaging material are stacked and removed when there are enough, without transporting a fixed number or a defined height. With all this information, this chapter provides answers to the following sub questions of the research:

1 *How is the current process flow arranged?*

2 *Which safety regulations are used in the current process?*

3 *What KPIs are currently in place, concerning the internal big volume logistics?*

The questions are answered by observing the process and having interviews with employees. Section 2.1 describes the different steps in the logistics, including the safety regulations for traffic. The KPIs are described in Section 2.2. Finally, a conclusion is made in Section 2.3.

2.1 Steps of the Logistics

In order to provide a clear explanation, the organisation of the logistics is described in three steps. These steps are: placing an order, delivering the order, and removing empty pallets and packaging material. After these steps, the safety regulations of this process are described.

The replenishment process is visualized in Figure 3. The rows represent the person who performs the job and the columns describe at which location the job is performed. Placing an order is done in the production area by the production worker and the SV milkrun driver. Next, the delivery process is performed by the BV forklift driver.

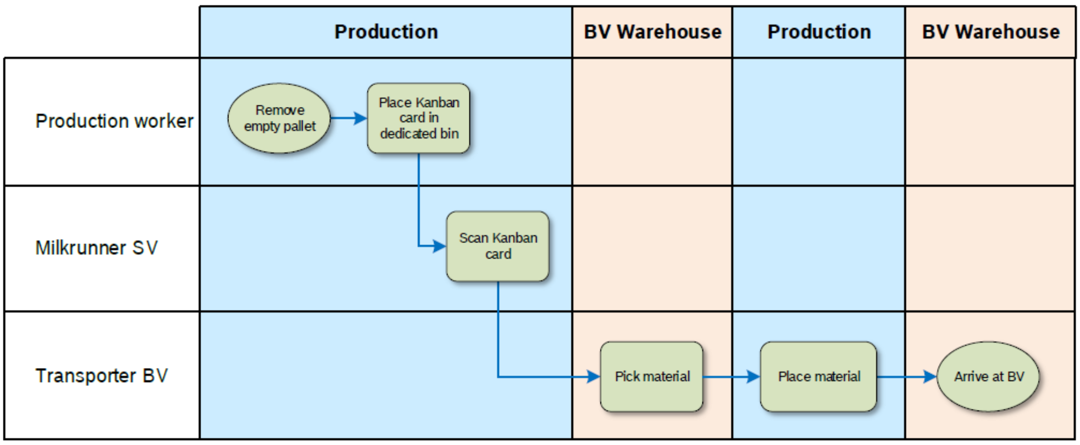

Figure 3: Visualization of the Current Logistics

2.1.1 Placing an Order

The production lines at Bosch Thermotechniek Deventer use a two-bin inventory system with a Kanban scheduling system. The two-bin inventory system makes sure that articles are always available at the production line. The Kanban scheduling system is triggered by scanning a Kanban card when one bin of a certain article is empty. In Figure 4, the two-bin system is shown. At the right half of the picture, a pallet is placed on a roller system. As can be seen, the roller system only contains one pallet. This means that for this article an order is placed for a second pallet, which will be placed behind the other.

Figure 4: Two-Bin System

When a pallet is empty, the Kanban card is placed in a collection box by the production worker. Next, the SV milkrun driver scans the card when it passes by the collection box. The Kanban system provides the warehouse department with an order for a certain article. In the warehouse, a printer prints the order such that forklift drivers can pick up this order and can start the delivery process.

Sometimes there is a forklift directly available, which means that the delivery process starts immediately. There is also a chance that the forklifts are already delivering another order, which means that the new order has to wait to be processed. Of course, there is no immediate problem when an order has to wait, since the production line has a two-bin inventory system.

2.1.2 Delivering the Order

The forklift driver takes the order from the printer and picks the matching article from the warehouse. When picked, the order is scanned and attached to the pallet, such that the article can be scanned again when the pallet is empty after use in production. Figure 5 shows the BV warehouse with the order printer in the bottom right of the figure. The warehouse uses a roller system to make sure that there always is a pallet at the front of the aisle.

Figure 5: BV Warehouse

The pallet is transported to the allocated production line. The forklift driver has to use roads that are meant for the forklifts. Some roads are limited to one-way traffic and some roads can be used for both ways.

Figure 6 shows the layout of the production environment. The driver arrives at the production area from the road at the bottom-left, right above the offices. This is the road from and to the BV warehouse. Once arrived at the production area, the driver will take the shortest route known by experience, when driving to the specified location. Each production line has several locations for the articles to be placed. These locations are placed all around each line.

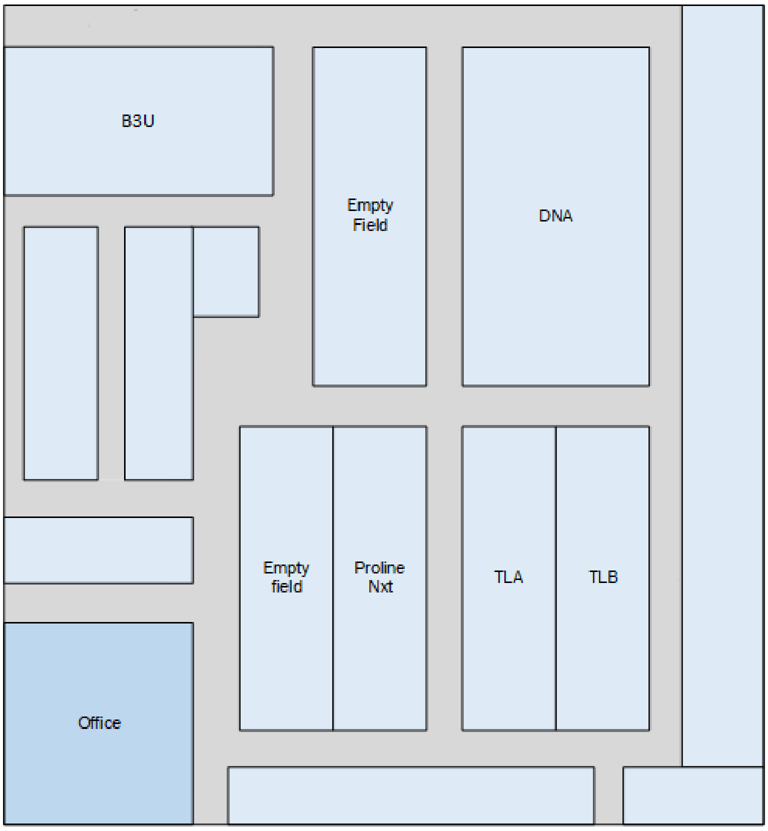

Figure 6: Layout of the Production Environment

Finally, the pallet is placed at the allocated location in the production line. The pallet will be placed behind the other pallet with the same article. Now, a new cycle can be started when this is needed.

2.1.3 Removing Empty Pallets and Packaging Material

When a Kanban card is scanned at the production line as described in Section 2.1.1, that pallet is empty and the packaging material is removed. Empty pallets and packaging material are both stacked at specified locations in the production line. This means that a production worker needs to transport both the pallet and the packaging material to its allocated location by hand. A location with pallets is shown in Figure 7. Once in a while, the forklift drivers pick the whole stack of empty pallets and remove it from the production environment. The same principle holds for the packaging material. There are no fixed moments and there is not a fixed number of pallets or a fixed height of packaging material that determines when the forklift driver needs to remove it. The driver checks the stacks when he comes along on his way back and takes it with him when he thinks that it is enough.

Figure 7: Empty Pallet Stack and Finished Goods

2.1.4 Safety Regulations

The safety for logistics in the production area is regulated by traffic rules and traffic signs. Despite these rules and signs, there still are a lot of situations that are not regulated. This lack of regulations creates unclear and sometimes unsafe situations.

Rules and Signs

The following traffic rules are applied:

- Forklifts and pedestrians should use their own lane. These lanes are next to each other and these lanes are separated by a white line.
- All forklift lanes can be used for two-way traffic.
- Pedestrians have to wear a pair of safety shoes and a safety vest.

To create more safety on busy roads, the lanes for forklifts and pedestrians are separated by a barrier with specified crossovers. Pedestrians are not allowed on the forklift lane at these places. Besides the traffic rules, convex mirrors are used on the side of the road to be able to clearly see other traffic around the corner.

Lack of Rules

The lack of rules can create unclear situations. No main roads with priority are defined. This does not have to be a problem if there for example is a rule that says all right traffic takes precedence, but this rule also is not present. Because of this, discussions arise about who is first and who takes precedence.

Another problem is that some lanes are too small for two-way traffic, while in spite of this no rules are used to say which way the traffic should go. When a forklift driver meets oncoming traffic on these lanes, the driver also uses the pedestrian lanes, which is not intended by the lines on the floor.

Most of the time, if such an unclear situation occurs, it only delays the flow of the traffic and will be resolved in a few seconds. However, sometimes it causes a collision, which is far worse. These collisions could have been avoided with clear traffic rules.

2.2 Current KPIs

At the moment, the Key Performance Indicator (KPI) used is a maximum replenishment time of 40 minutes for delivering BV materials. This is based on the fact that a number of materials are used that require a replenishment time of 40 minutes, but not all materials require such a small time window. In fact, the majority of the BV materials have a larger time window. Therefore, the value of 40 minutes is not the best way of measuring the performance. A material-specific replenishment time provides better insight in how many materials are delivered on time. Besides that, there is no data on the performance of replenishment within 40 minutes.

To cope with the lack of data on the replenishment performance, a simulation study is performed by the author to analyse the performance of the current situation. For this simulation study, the KPI used is the maximum replenishment time of an order for the production lines, concerning the BV materials. The maximum replenishment time is material-specific, since materials have a different number of items placed on a pallet. The alternative situations are compared with the current situation. Therefore, the new logistic system should have the same performance of the replenishment time as the current situation. While this is the hard criterion, a solution with a smaller replenishment time will be marked with a higher performance score.

The required replenishment time per material is calculated based on the tact time of that specific production line and the number of units of that material on the pallet. This can be done, since the materials are used sequentially. The following equation is used:

$$Required\ replenishment\ time = Number\ of\ units\ \cdot\ Tact\ time$$

As this is the basis, there is an exception. Not all materials are used for all finished products. Therefore, the percentage of finished products in which these materials are used is determined by analysing historical data. For these materials, the following equation is used:

$$Required\ replenishment\ time = \frac{Number\ of\ units\ \cdot\ Tact\ time}{Percentage\ of\ finished\ products}$$

2.3 Conclusions

The current BV logistics starts when a production worker places a Kanban card in a collection box. The production worker also removes the packaging material and puts the empty pallet on a dedicated stack at a location in the production line. A SV milkrun driver scans the Kanban cards that are in the collection box when the he drives past. Next, two forklift drivers both pick a single pallet with materials and transport the pallet to the location in the production area. The picking of materials is done by a first come first served principle, based on the orders that are waiting at the printer. When there are more than seven orders waiting to be picked, a third forklift driver is deployed who only picks materials. If the third employee is used, the other two forklift drivers only transport the materials to speed up the delivery process. When the printer is empty again, the process switches back to two drivers.

Due to a lack of rules, all roads are used for two-way traffic. This is in contrast to the allowed traffic directions, since some roads are limited to one-way traffic. The exact rules on the traffic directions are discussed in Chapter 4.

No registration is made concerning the performance in terms of meeting the required replenishment times. Due to this lack of data, a simulation study is needed to analyse the performance of the current situation. Analysing the current situation thoroughly provides insights in understanding the process. Furthermore, the simulation study can be validated by the current situation and data is obtained for comparing the proposed solution methods in future situations. The analysis on the performance of the current situation is described in the next chapter.

Chapter 3 – Current Performance

The performance of the current situation is analysed by performing a simulation study. The simulation study is based on the design of the BV process and is filled with parameters and variables considering the production planning of 2018. This production planning is shown in Appendix A. After the design of the process, experiments are executed to simulate the behaviour of the system. With the results, this chapter provides answers to the following sub question of the research:

4 What is the performance of executing big volume orders, in terms of lead times?

Question four is answered by executing the experiment of the current situation in the simulation model. Parameters and distributions are needed for this model, which are collected by analysing data and by interviews with employees. In Section 3.1 the simulation model is explained. Section 3.2 goes further into the simulation study. Finally, a conclusion is made in Section 3.3.

3.1 The Simulation Model Construction

Tecnomatix Plant Simulation is used to create the Discrete Event Simulation (DES) model. The layout of the production plant is visualized in this DES model in order to be able to perform an experiment, concerning the performance of the current BV supply. The results of this experiment are compared with the performance of new situations that are analysed. The new situations are also modelled in the DES model and are described in Chapter 5, including the explanation of scenarios and interventions.

3.1.1 DES Model of the Process

The layout of the production area is visualized in the DES model in order to perform experiments. The visualization is shown in Figure 8. The model uses pathways on which the transporters can move.

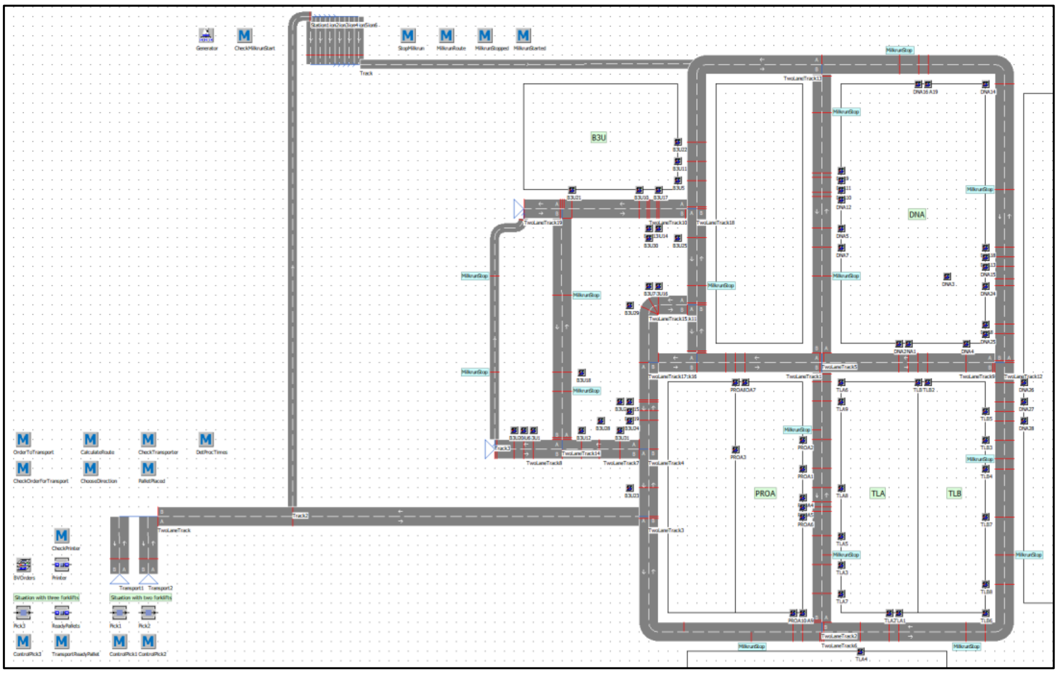

Figure 8: Layout of the Production Area in the DES Model

In general, the simulation is performed as follows. The BV supply is executed by forklifts which get the order and pick the pallet from the warehouse in the bottom left corner. Next, the material is transported to the correct place in the production area at the right half of the figure. The SV supply is executed by milkruns that are positioned in the top left corner and drive through the production area by following a time schedule for the start time of every cycle. When driving through the production area, the milkrun follows a fixed route.

Level of Detail of the Model

As mentioned, several logistic flows are relevant for the simulation, but the level of detail is different for each flow as the importance for each flow differs together with the effort to get all the information.

The BV supply is the main subject of this simulation study. Therefore, this logistic flow is codified in such a way that all handling of the materials is implemented in the model, based on historical data or knowledge of experts. In this way, the relevant aspects of the BV orders can be analysed and the model can be validated. The SV supply is the major logistic flow in the production area, and therefore it is the most important flow for disturbing the BV supply. This flow is modelled by using the predefined route as used in practice, together with the time schedules that are used when a certain number of milkruns is deployed, based on the workload in a certain week. The level of detail concerning process times of picking and placing both BV and SV materials is described in Section 3.1.2.

All other traffic is simulated as random traffic congestion, as these flows are not structured and can disturb the BV supply any time for a short period. These randomly simulated events represent the flows of waste, FG, and pedestrians who cross roads.

Control Panel of the Model

Besides the layout of the production area, the DES model also contains a control panel that creates the data needed and that keeps track on variables during the experiment. The control panel is shown in Figure 9.

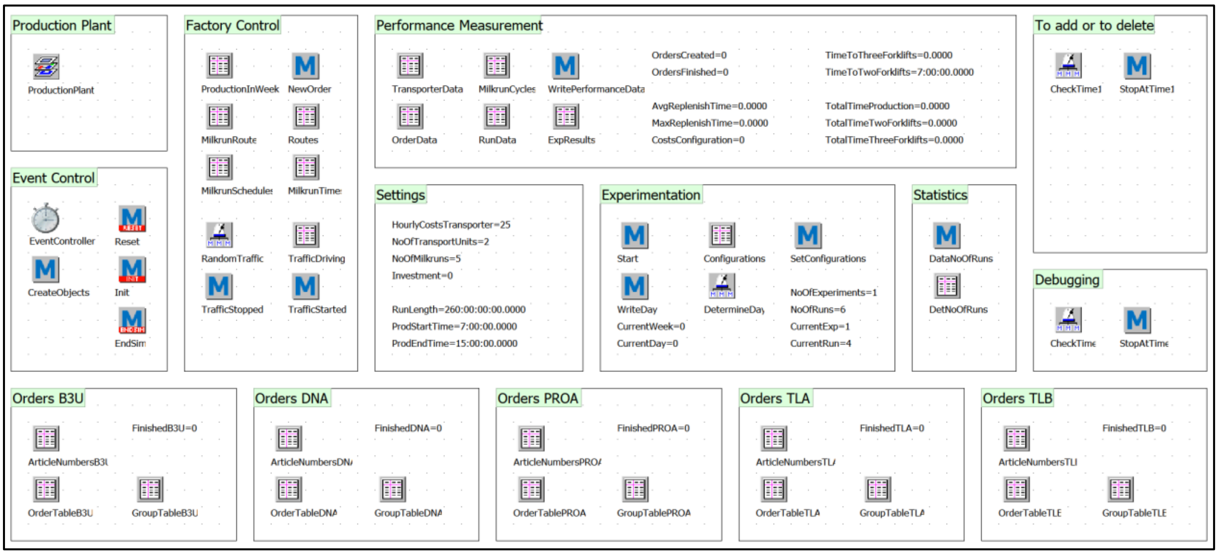

Figure 9: Control Panel of the DES Model

The control panel includes several aspects for performing the experiments. The different aspects are categorized and shown under a green label with information about the purpose of that category. The categories are explained on the next page.

Production Plant
The production plant contains the frame with the layout of the production area on which all events happen. On this layout, the movements of the orders and transporters can be shown.

Event Control
The event control provides the possibility to execute several experiments if this is desired. It also controls going through the predefined number of runs during an experiment.

Orders Production Lines
The input data of orders is categorized per production line and written in the tables at the bottom of the figure. These tables are the basis of the simulation as they trigger the need of a material to be replenished somewhere in the production area at a certain moment in time.

Factory Control
The major part of the settings to control the factory includes the workload of the production lines per week with the schedule of the milkruns during those weeks. Furthermore, these settings include the other traffic types that disturb the transport of pallets at random generated moments.

Settings
The settings of the experiment provide the run length of the simulation together with information about the transporters and the production times. These settings may change during a run of the experiment, but they are used as input for the production plant frame.

Experimentation
The experimentation includes a start button to start the experiment and provides information about the progress of the experiment. During the experiment, the model uses all above aspects in order to correctly simulate an entire year.

Performance Measurement
As mentioned in the introduction of this chapter, the simulation is based on the production planning of 2018. Therefore, the simulation length is one year. To keep track on the performance of that year, the realized replenishment times and other relevant aspects are written in tables and variables. Several runs are executed per experiment which all contain their own data. Next, this data is used to calculate the results of an experiment.

Statistics
Output data of the simulation is exported to Microsoft Excel in order to statistically calculate the number of runs needed per experiment. This calculation makes sure that the experiment gives reliable results and that these results are not generated by coincidence.

Debugging
Debugging the simulation is done during construction of the model for verification of the model so far at that moment in time. It can also be used to stop the simulation at a predefined moment if it is desired to see results during the experiment.

3.1.2 Input Parameters and Variables

The model is filled with input data in order to perform a realistic simulation study. Data was needed for codifying the following aspects:

- The structure of transporting materials;
- The demand for orders in the production area.

Structure of Transporting Materials

To build the structure of transporting materials to the production area, the following aspects need to be modelled: the capacity planning and schedule of the transporters in the production area, which routes are driven, and the process times of picking and placing materials.

Planning BV Transporters

For the planning of BV transporters, every aspect is modelled according to rules that are followed in practice. These rules are implemented in the DES model. The assumption is made that the employees work according to these rules. For the process times of picking and placing materials, a simplification is made by determining the times by using the PERT method, which is further explained in this section.

In conversation with the senior team leader, constructing the structure of the BV transporters in the following way represents best the way of working in practice (B. Evers, personal communication, October 9, 2018). During the production hours, two forklift drivers transport the orders with the BV materials from the warehouse to the production area. A printer in the warehouse prints the order and the transporters pick and transport the material belonging to that order. No more than one material is picked and transported at a time. The orders are picked following the First Come First Served principle (FCFS). Next, the orders are transported by following the shortest path to the destination. This is easily done, since the orders are transported one by one. When a transporter arrives in the warehouse and sees that more than seven orders are waiting at the printer, a third forklift driver is deployed who only picks materials until the printer is empty again. In case of the third driver being deployed for picking, the other two drivers only transport the materials to the production area.

Besides the overall structure of the BV transporters, process times of picking and placing BV materials are also required in the DES model. There is no historical data concerning these process times. Therefore, the process times of picking and placing are determined by the Program Evaluation and Review Technique (PERT). This method determines the processing time of an operation when there is a lack of data on this subject. The method uses three values: an optimistic, an expected and a pessimistic value. With these values, the PERT method determines the parameters for the Beta distribution which can be used for determining the processing time of the operation (Ravi Shankar et al., 2010).

The PERT method is used for the process times of both picking the material in the warehouse and placing the material in the production area. The optimistic, expected, and pessimistic value are called a, b, and c, respectively. The PERT method uses the following equations to determine the parameters (alpha and beta) for the Beta distribution:

$$\alpha = \frac{4b + a - 5c}{a - c}$$

$$\beta = \frac{5a - c - 4b}{a - c}$$

These parameters are used in the DES model to create the processing time for the operation when a material is picked or placed. The values a, b, and c are determined by discussions with experts and little data is collected to check the values which were given by the experts. The processing times according to the experts are shown in Table 3. The values are in seconds.

Operation	Optimistic	Expected	Pessimistic
Picking BV in warehouse	60	105	120
Place BV in production area	15	60	120

Table 3: Processing Times for Picking and Placing BV Materials

SV Milkrun Schedule
As mentioned, the SV milkrun process is not implemented with the same level of detail as the BV process. For implementing the SV milkrun structure in the DES model, assumptions were needed concerning the picking of materials in the warehouse. The other aspects concerning delivering materials and the number of milkruns planned through the entire year are simplified, but implemented according to structures that are used in practice.

It is known that six milkruns are deployed when all production lines are operative at full speed. It is also known which production line is operative at full speed, half speed, or not operative in each week, based on the production planning. Besides this data, analysing the total number of orders per production line shows how much every production line contributes to the workload of the milkruns if all production lines are fully operative. With all this information, the number of milkruns deployed is calculated for every week and used in the DES model. The calculation is found in Appendix B.

As shown in Table 4, it is possible to use three to six milkruns. For each situation, a different schedule is made. The table shows the schedule for the first jobs of the day in every situation, based on the assumption that a milkrun is returned to its station within an hour. This assumption is explained below. Each job is a complete cycle of the milkrun operations, in which the milkrun follows a predefined route in the production area and in which it picks materials in the warehouse.

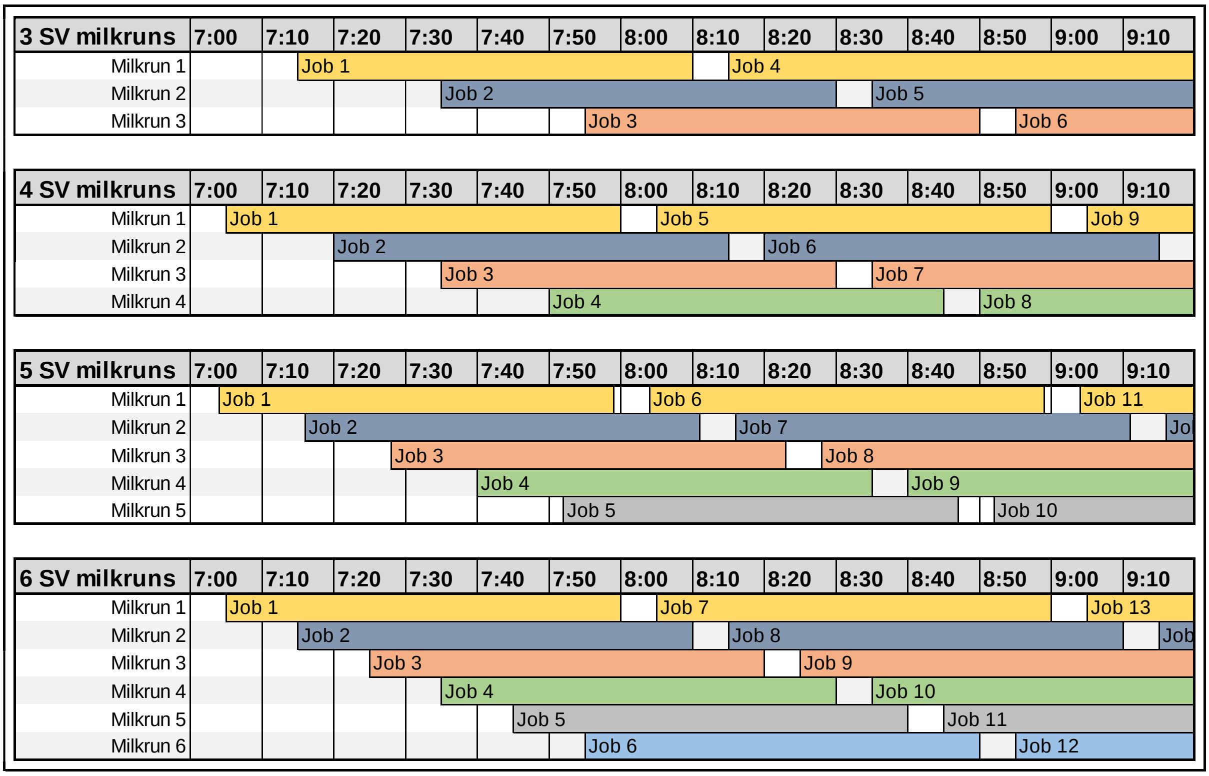

Table 4: Scheduled Cycles for the Milkruns

After a discussion with the senior team leader, the assumption is made that the milkruns always return to their starting position on time, which is before the start of the new cycle for that specific milkrun number (A. Bergman, personal communication, November 16, 2018). According to this assumption, picking of the materials is not taken into account in the DES model. This can be done, since picking is executed in a separate area where no disturbance to the process of the BV transporters can occur. Therefore, in the model the milkruns return to the starting position of the cycle after a cycle through the production area is completed.

The process time for placing materials in the production area is calculated on the basis of the PERT method, just like the pick and place processing times for the BV transporters. The calculated parameters are used in the DES model. Again, the values a, b, and c are determined by discussions with experts. The only difference is that no data is gathered to check the values which were given by the experts. This is not done, because the implementation of the SV milkruns already is an approximation and checking the values for minor changes will not make a difference in the performance, while it is time consuming. The processing times according to the experts are shown in Table 5. The values are in seconds.

Operation	Optimistic	Expected	Pessimistic
Place SV in production area	45	60	75

Table 5: Processing Times for Placing SV Materials

Other Traffic

The other traffic consists of the following flows: the disposal of waste, the storage of FG, the return of pallets and packaging, and crossing pedestrians.

There is no data available that can be used for implementing these flows accurately in the DES model. One employee is responsible for the disposal of waste and one for the storage of FG. These workers drive through the production area to check where a load is ready for transport, but the workers do not know at which locations a load is ready. Thus, the workers do not follow a fixed route or schedule.

For the return of pallets and packaging material, the same transporters are deployed as for the supply of BV materials. On their way back, the transporters check if a stack of pallets or a stack of packaging material is high enough to be removed from the production area. Again, there are no fixed moments or a fixed order in which these activities are performed.

Pedestrians can cross roads randomly. As an example, the production area can be shown to a group of visitors or employees are walking through the production area when going to a meeting. These events are not structured.

Because of the random behaviour of these types of traffic, collecting the data for modelling these flows realistically will be time consuming, while these flows create minor traffic compared to the supply of BV and SV materials. Therefore, these several flows are modelled as random disturbances to the BV transporters and the SV milkruns.

Demand for Orders in Production

The production lines need BV and SV materials. In contrast to the BV demand, the SV demand is not modelled in a material-specific way. This choice is made, since the SV supply is not the main subject of the DES model and otherwise it would make the model more extensive and more complex as the SV supply includes far more materials than the BV supply. The SV demand is modelled in such a way that the SV milkruns drive along their predefined route and stop at predefined locations for a certain period of time as explained in the sub section ‘Structure of Transporting Materials’. The locations for the milkrun are determined in conversation with the senior team leader (A. Bergman, personal communication, November 16, 2018).

The BV demand is the basis of the entire simulation, since this triggers the BV transporters and determines the workload. The demand is based on the production planning and the number of articles on a pallet. Therefore, the following data is needed: the production planning and the material-specific replenishment times. Furthermore, the position of the BV locations in the production area is needed in order to direct the transporter to the correct position in the production area.

Material Locations
The positions of BV materials in the production area in the DES model are the exact locations used in practice. The positions are determined by measuring the distances in the production plant. With this information, the transporters are directed to these locations by following the shortest path.

Production Planning
The BV demand is codified, based on the production planning in order to provide the model with a realistic production planning. As mentioned, the production planning is shown in Appendix A. The planning shows in which weeks a production line is operational at full speed, at half speed, or not operational.

BV Replenishment Cycles
As mentioned in Section 2.2, the required replenishment time for a certain material is based on the number of articles on a pallet and the tact time. The replenishment cycles of a material have the exact same time interval as the required replenishment time, since the pallets contain the same number of articles. Therefore, the replenishment cycles are codified in such a way that the orders for the entire year are scheduled in advance, using the following equation if a material is used for all finished products:

$$Replenishment\ cycle\ time = Number\ of\ units\ \cdot\ Tact\ time$$

If a material is not used for all finished products, the following equation is used:

$$Replenishment\ cycle\ time = \frac{Number\ of\ units\ \cdot\ Tact\ time}{Percentage\ of\ finished\ products}$$

For every production line, a table is filled with orders scheduled until the end of the simulation. Considering the scheduling of orders, there are three types of materials:

- Materials that are used for every finished product;
- Materials that are not used for every finished product;
- Materials that exclude each other, but are used for every finished product for a certain period of time.

The first type of materials consists of independent materials that are used for every finished product. Therefore, the orders are scheduled through the entire year of the simulation with a cycle time calculated by the first equation.

The second type of materials also are independent materials, but these are not used for all finished products. The products for which these materials are (not) used, can be produced at random moments. Therefore, the assumption is made that the finished products that do not need a certain material are evenly spread through the simulation. Historical data on the realized orders is analysed to get the percentage of finished products for all materials. With this information, the orders are scheduled through the simulation with a cycle time calculated by the second equation.

The last type of materials consists of materials that exclude the need of each other, since they are functionally the same. To make this more understandable, a numerical example is given:

> *Suppose there are two types of covers for a certain type of boiler: cover X and cover Y. The production plan for a certain day is 50 boilers. 80 per cent of the boilers need cover X, while 20 per cent need cover Y. At first, 40 boilers with cover X are produced, after which 10 boilers with cover Y are produced.*

All materials are analysed to find out which materials are functionally the same. The materials with the same functionality are grouped and the fraction of each material in the group is calculated. Next, the orders in the DES model are scheduled with time windows within a day, corresponding with the percentages in the group. Within those time windows, the need of a material is 100 per cent. Therefore, the orders are scheduled with a cycle time calculated by the first equation.

3.1.3 Verification and Validation

The credibility of the model is an important issue when using a simulation study as a solution method. Therefore, verification and validation are important in order to show the stakeholders that the DES model does what it is expected to do and that it represents the system well. In order to verify and validate the model correctly, and thus to build a credible model, techniques are followed that are presented by experienced researchers (Law, 2015).

The stakeholders are constantly updated on the status of the DES model, by visualizations of the model during the construction phase. The level of detail is discussed whenever necessary and assumptions and simplifications are proposed and discussed when needed. This approach contributes to a model that is trusted by all stakeholders.

Verification

Verification is about determining whether the model is built correctly according to the conceptual model, i.e. the correctness of the program. This contains debugging the entire DES model, such that the conclusion can be made that the model behaves like it is intended (Law, 2015).

Several techniques are used to verify the DES model:

- Multiple checks are performed during the coding phase when a new aspect of the system is programmed. These checks include debugging the method that is written and keeping track on attributes of the moving unit under consideration when going through the system.
- The overall flow of moving units and the overall output of the model are also checked when a new aspect is implemented.
- The model is programmed in an object oriented way as much as possible. An object oriented way of programming means that multiple objects of the same type are standardised when performing a similar task. In that way, changing one of the objects will also change the other objects of that type. By doing this, less mistakes are made and when a mistake is made, it is easier to find the cause of the error.
- Small test models are made to figure out how a certain aspect should be implemented in the model. This is done, since changing back an implemented piece of code can be more difficult as the model becomes more complex. When the test model works fine, the structure of this simplified model can be used for the complex model of the system.

Validation

Validation is about determining whether the model represents the system accurately for the objectives of the study. The model is valid if an approximation of the actual system is made, which means that the results of the objectives should be approximately the same as the results of the system (Law, 2015).

The number of orders that have to be delivered, determine the workload and therefore are the basis for the performance of the overall model. As mentioned, the generated orders in the DES model are based on the production planning of 2018. This means that the run length of the DES model needs to be a year. With the run length given, comparing the realized number of orders with the generated number of orders provides insight in the validity of the model. As the DES model creates BV orders based on the theoretical maximum capacity of the production lines, the realized number of orders are converted to the theoretical maximum number of orders as well. Every production line has its standard efficiency and on top of that, some unexpected losses have happened through the year. These are taken into account. An overview of the realized and generated number of orders is shown in Figure 10.

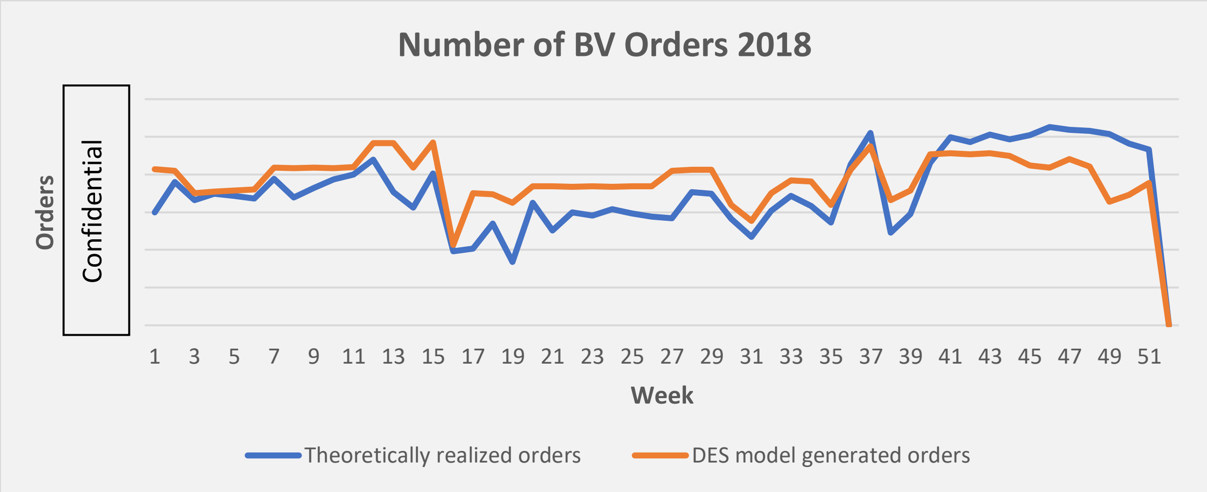

Figure 10: Number of BV Orders 2018

As one can see in the figure, the DES model and reality show approximately the same trend for the BV orders. The general variation of high and low production through the weeks is roughly followed by the DES model. However, the total number of orders in the model is higher than the actual number of orders. The total number of orders for both situations is shown in Table 6. The relative difference is 7.63%. In discussion with the stakeholders, the conclusion is made that this difference is acceptable. Therefore, it is assumed that the DES model is valid concerning the workload that is generated.

Situation	Total orders	Difference to reality	Relative difference
Reality	Confidential		-
DES model			7.63%

Table 6: Comparing the Total Number of Orders

Besides the workload that is generated, the logistics should be valid as well. However, validating the logistic system with quantitative techniques is more complicated, since little data is known and providing insight in this system is one of the main subjects of this research. The implementation of the operational rules used in practice is verified, and interviews with team leaders have made clear that these rules are followed well in practice. The implementation is discussed with the stakeholders of Bosch Thermotechniek Deventer, in order to make sure the model is a credible model. With this information, the behaviour of the logistic system in the DES model is considered to act according to the behaviour of the system in practice.

3.2 The Simulation Study

Now that the structure of the DES model has been discussed, it is important to understand how the model is used to get reliable output that represents the reality well. At first, the experimental design is explained. This includes the requirements to perform a statistically sound simulation study. Next, an explanation is written of the experiments performed. Finally, the results of the simulation study are shown. As mentioned earlier, these results concern the current BV logistics and are required for comparing the performance of the proposed future situations which are discussed in Chapter 5.

3.2.1 Experimental Design

The experimental design explains the required settings for the simulation study. These settings are the run length of the simulation, the warmup period, the number of runs per experiment, and the performed experiments.

Run Length

The run length of the simulation study is one year, since the DES model is built on the production planning of 2018. This is done, since simulating an entire production year includes the performance during high and low seasons and since validation can also be done for seasonal trends.

Warmup Period

The length of the warm-up period depends on the type of system that is modelled. According to literature, a system can be terminating or non-terminating. For both situations the system contains a certain period with transient behaviour and after that a period with steady-state behaviour (Law, 2015). Transient behaviour means that the performance depends on the initial conditions, while steady-state means that the performance does not depend on the initial conditions anymore.

Concerning the warmup period, it is important to understand the behaviour of the system. The production is operative eight hours per day, which indicates that the system has a natural end event, being the end of every production day. However, the next day production starts with the exact situation as it ended the last day. This means that the process is non-terminating and therefore the steady-state behaviour is analysed. To cope with the transient behaviour of the DES model, a warmup period is used which makes sure that statistics are only gathered during the steady-state of the system.

The length of the warmup period is determined using Welch's graphical procedure (Law, 2015), which is shown in Figure 11. This procedure uses a moving average for a specified range of values which eventually flattens out the performance indicator under consideration. The KPI used for this procedure is the replenishment time of orders. According to the graphical procedure, the system is in its steady state after one production day. Therefore, the warmup period of the DES model is set to one day.

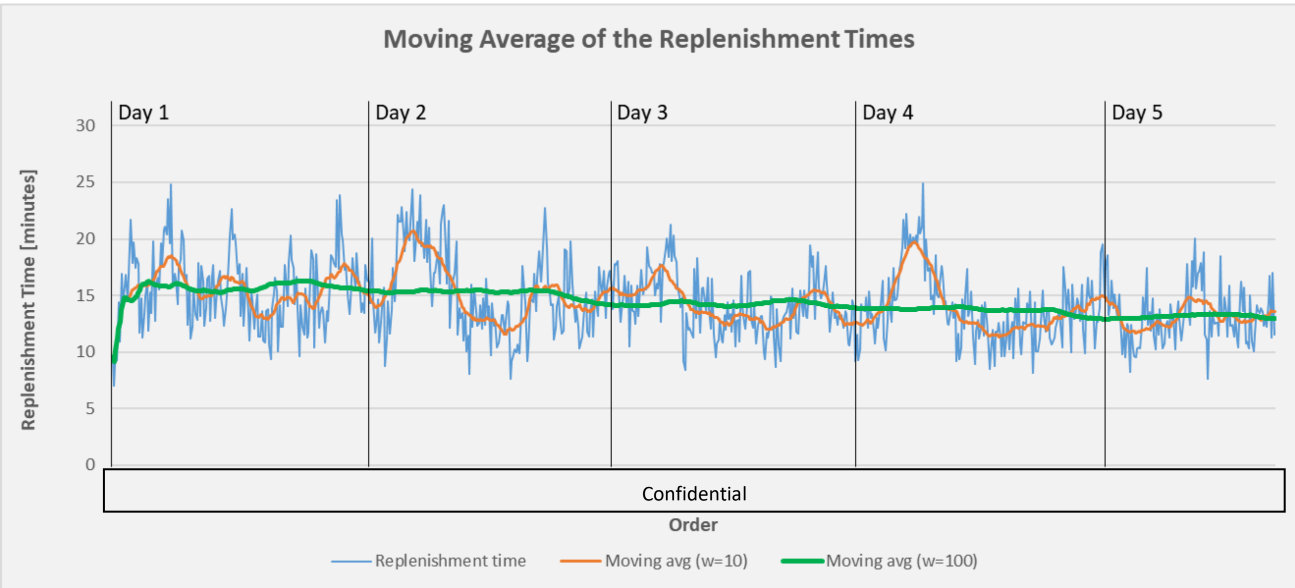

Figure 11: Warmup Period according to the Welch Method

Number of Runs per Experiment

In order to obtain statistically sound simulation results, the number of runs per experiment is an important factor. A run is one repetition of simulating the system. The input of the DES model partially depends on random variables. As the output of the simulation study is a complex function of the input, the output also depends on random variables. To cope with the random behaviour of the model, several runs are performed per experiment. The calculation of the number of runs required per experiment is explained below. The simulation study uses Common Random Numbers (CRNs) in order to be able to compare the different experiments. CRNs ensure that the first run of an experiment is comparable to the first run of every other experiment, and the same principle holds for the second run, the third run, and so on (Law, 2015). Eventually, an experiment is comparable to every other experiment that is simulated in the same DES model.

The number of runs required is calculated by estimating the mean of a certain output variable with a specified precision. Each run provides a point estimate of the mean for the output variable. With these point estimates, a Confidence Interval (CI) of the mean can be calculated. A CI is the expected range in which the mean of the output variable will lie, with a predefined certainty. A 95%-Confidence Interval (95%-CI) for example, calculates the range in which the mean lies with a confidence level of 95%. The CI for the mean, when the variance is unknown, is calculated with the following formula:

$$\left[\bar{X} - t_{n-1,1-\frac{\alpha}{2}} \cdot \frac{S}{\sqrt{n}}\,, \bar{X} + t_{n-1,1-\frac{\alpha}{2}} \cdot \frac{S}{\sqrt{n}}\right] \textit{ in which}$$

$$\begin{aligned}
&\bar{X} = \textit{the sample mean}\\
&S = \textit{the sample variance}\\
&n = \textit{the number of runs}\\
&\alpha = \textit{alpha, the confidence level of the CI}\\
&t_{n-1,1-\frac{\alpha}{2}} = \textit{the t value for the Student's t distribution, where}\\
&\qquad n-1 = \textit{ the degrees of freedom}\\
&\qquad 1-\frac{\alpha}{2} = \textit{the significance level of one tail}
\end{aligned}$$

The acceptability of the confidence width depends on the sample mean. When the sample mean is higher, a certain confidence interval can be accepted while this interval is not accepted for a smaller sample mean. Let this be explained by the following numerical example:

> *Suppose the CI-width of 30. When the sample mean is 50, the CI is [20, 80]. However, when the sample mean is 500, the CI is [470, 530]. Obviously, the latter of the two situations is a far better prediction.*

To cope with this, the relative error is calculated. This is the half of the CI-width relative to the mean. In simulation studies, the obtained relative error should be sufficiently small. This is calculated with the following formula:

$$\frac{t_{n-1,1-\frac{\alpha}{2}} \cdot \frac{S}{\sqrt{n}}}{\bar{X}} < \gamma' \textit{ in which}$$

$$\begin{aligned}
&\gamma = \textit{gamma, the estimate for the relative error}\\
&\gamma' = \frac{\gamma}{1+\gamma}
\end{aligned}$$

Empirical evidence shows that gamma should be lower than 0.15 (Mes, 2017). In order to calculate the required number of runs, the confidence level is chosen to be 95% (which means that an alpha of 0.05

is used) and the estimate of the relative error is 5% (which means that a gamma of 0.05 is used). Literature shows that both values are commonly used in simulation studies (Law, 2015).

Figure 12 shows the required number of runs per experiment. The relative error is calculated for the output variable ‘average replenishment time of the orders’ as this is an important output variable for the overall model and it is one of the most fluctuating variables between the different runs. As one can see, four runs are required to make sure that the obtained relative error is sufficiently small. Therefore, each experiment contains four runs to cope with the random behaviour of the DES model.

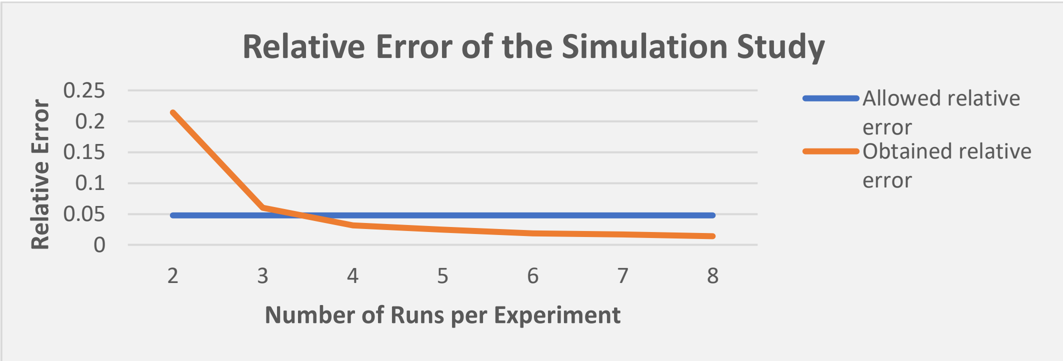

Figure 12: Relative Error of the Simulation Study

3.2.2 Experiments

Experiments are performed for the DES model described in Section 3.1.

As described in Section 2.1.5, some roads are too small for two-way traffic while in spite of this all roads are currently used for two-way traffic. In order to let traffic correspond with the width of the roads, some traffic directions are changed from two-way to one-way traffic. The current and future traffic directions are shown in Figure 13 at the left and right half, respectively. The red and green arrows show which two-way roads are changed to one-way. On the next page, an explanation is given on the direction determined for the green arrows.

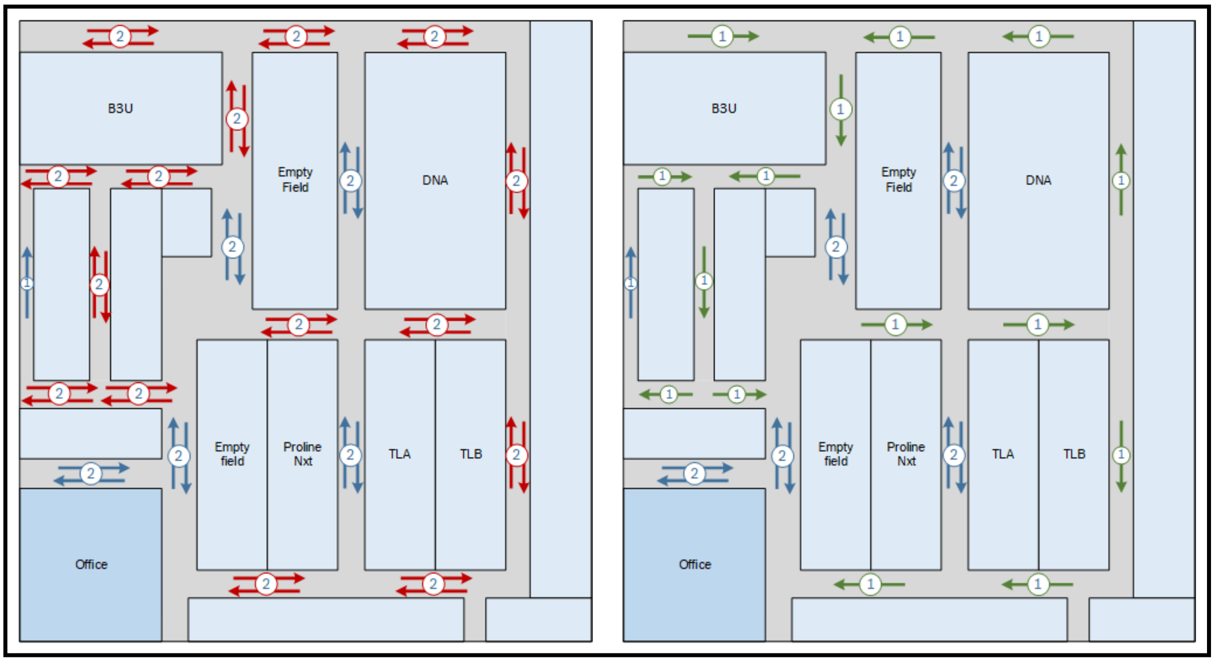

Figure 13: Current (left) and Future (right) Traffic Directions

Section 4.1.1 explains how the one-way and two-way roads are determined. The direction of the one-way roads are determined by common sense and the directions of other traffic. As destinations of orders are spread around all roads, the overall distance is minimized with the mid-horizontal road to the right and the upper and lower horizontal roads to the left or vice versa. This mid-horizontal road to the right and the other two to the left is the best suitable with the SV milkrun route, which makes sure that other traffic is the least interfered by the new rules.

As delivering orders in the current situation is in contrast to the traffic rules that should be followed, it also is important to know what the performance would be if the forklifts are still deployed, but then using the future traffic directions. This is important for comparing the situation with forklifts to proposed future situations. Because of this, two experiments are performed for the DES model concerning the current situation with forklifts:

- The current situation with the current traffic directions;
- The current situation with the future traffic directions.

In the next section, the results of the current situation are shown.

3.2.3 Results of the Study

The experiments concerning the current situation simulate the behaviour of the transporters according to the current way of working in practice. Both experiments contain four runs in order to provide statistically sound results. These results can be used for comparing the proposed future situations.

Table 7 shows the results of both experiments. For validating purposes, the replenishment times and the costs are discussed internally. With the discussion, these values are assumed to be true, which provides a good basis for comparing the proposed future situations, described in Chapter 5.

In the table, one can see that the replenishment times are longer when the future traffic rules are followed. This is due to the fact that more distance has to be travelled per order. In itself this does not have to be a problem. However, the number of orders that has been delivered too late has risen, which means that the service level is lower. Therefore, the performance of the current situation with the future traffic rules is the basis for comparing the proposed future situations. This is done, since the future traffic directions have to be followed whether forklifts are replaced by another system or not. Using this basis, the ROI of proposed future situations can be determined together with other important factors. As already mentioned, the comparison is performed in Chapter 5.

Simulation study	Avg. replenish time [min]	Total number of orders	Orders within replenish time	Orders too late per year	Yearly costs of process	Investment costs	Production loss per year	Service level
Current Situation - Current Traffic Rules	15.0	Confidential						99.990%
Current Situation - Future Traffic Rules	17.6							99.957%

Table 7: Results Simulation Studies of the Current Situation

The yearly costs of the process accounts for labour costs and equipment costs, as equipment is leased. Table 8 shows a detailed overview of the yearly process costs.

Simulation study	Labour costs	Equipment costs
Current Situation - Current Traffic Rules	Confidential	
Current Situation - Future Traffic Rules		

Table 8: Results of the Current Situation - Costs Details

The loss of production is the value of the time that a production line has come to a hold, since the required material is not delivered and production workers cannot build CH-boilers. Although the service level is high, the loss of production per year is significant when there is a slight deviation in the service level. Therefore, a high service level is required. Below, this is explained further.

When a production line has come to a hold because of a material that is not delivered, a call is made and an employee steps in to directly deliver the material to the production line. The material has to be picked and delivered. In order to calculate the value of the lost production, the assumption is made that such a delivery takes ten minutes, which is converted to a value in money by calculating the total time that employees are not able to work. As twelve employees work at a production line, the total time is the delivery time multiplied by twelve employees. This method is discussed with a senior team leader (B. Evers, personal communication, February 26, 2019).

To put the impact of production loss in perspective, the loss of production is calculated for a 95% service level as this is common to use. In that case, around *(confidential)* orders are delivered too late. The costs of production loss for a service level of 95% are the following:

$Costs\ of\ production\ loss$
$=$
$=$ Confidential

The impact of the production loss is discussed with the stakeholders and a decision is made that the AGV or milkrun system needs to have a service level of at least 99%. Having a threshold lower than the current performance creates the opportunity to come up with systems that require less capacity. In the end, the reduced capacity should make up for the difference in the service level and of course a high threshold is needed. Otherwise the process is disturbed too many times.

3.3 Conclusion

The performance of the BV logistics is measured by performing a simulation study in a DES model. The entire BV process is simulated together with all other traffic. Orders are planned, based on the real production planning of 2018. Next, simulating the BV process is done by taking all rules into account that are applied in practice. The orders that are generated, are validated by the orders that have been delivered in reality. For the logistics, quantitative validation is hard, as getting insight in the quantitative performance is one of the main subjects of this research. Therefore, the part concerning logistics is validated by discussing the implementation of the rules applied in practice. After discussions with the stakeholders, the model is assumed to be valid.

Calculations are made for the experimental design, to make sure that the simulation study represents the reality. The current situation with the current traffic rules is simulated, and the process is simulated with the future traffic directions. The future traffic directions have to be followed whether forklifts are replaced or not, since this is in line with the safety regulations that should be maintained.

Considering the performance of the process, the conclusion can be made that it performs well. The average replenishment time of the current situation is 17.6 minutes, with a service level of 99.957%. The yearly costs of the process, concerning labour and equipment costs, is *(confidential)*. Besides the process costs, the yearly loss of production is *(confidential)*, as production workers have to wait *(confidential)* times for materials to be delivered. Therefore, the total yearly costs are *(confidential)*.

Each percentage of reduction in the service level results in *(confidential)* of extra yearly costs. The threshold for the service level of future situations is discussed with the stakeholders and set to 99%.

Chapter 4 – Literature Review

The literature review presents possible options for the topics that are relevant for this research. Now the current situation is known, it is important to get familiar with existing options in order to come up with a new process of the logistics for both a milkrun system and an AGV system. For that, currently used approaches in manufacturing environments are explored and theoretical frameworks for certain calculations are analyzed. The following sub questions are answered in this chapter:

5 *Which (safety) regulations should be used for all traffic in production?*

6 *Which methods can be used to implement milkruns or AGVs in logistics?*

7 *Which pick and place options exist when using a milkrun or AGV system?*

8 *How can the control of a milkrun or AGV system be organized?*

The questions are answered by searching for external information on the relevant topics. Both theoretical information from papers and practical information from non-academic sources are analysed. Section 4.1 covers the regulations for traffic, in which the traffic directions and routes are the main subject. The organization of the BV logistics, which covers the possibilities to implement milkruns or AGVs and to control the process, is described in Section 4.2. Next, more specific options for the handling of materials during the process are explained in Section 4.3. Finally, Section 4.4 formulates the conclusions found during the literature review.

4.1 Regulations for Traffic

Traffic has to be regulated in order to safely and efficiently deliver materials to the production lines. Recall that at the moment, all roads are used for two-way traffic while some roads are limited for one-way traffic. For safe driving circumstances, clear rules on traffic directions are needed, in order to create a situation in which employees know what roads are two-way and what roads are limited to one-way traffic. Given the possible traffic directions, an efficient route needs to be determined for delivering materials to the production lines.

4.1.1 Traffic Regulations

The Arbowet – the Dutch regulations on working conditions, concerning the well-being of employees – provides directives on the width of internal roads when using those roads for one-way or two-way traffic (deArbocatalogus, 2015). The required width for these two situations is the following:

One-way roads: $Req.width = width\ of\ widest\ vehicle + 60\ cm$
Two-way roads: $Req.width = width\ of\ widest\ vehicle \cdot 2 + 90\ cm$

Within Bosch Thermotechniek Deventer, the widest vehicle in the production environment has a width of 108 centimetres. Therefore, according to the Arbowet, the required width for the roads are the following:

One-way roads: $Req.width = 108 + 60 = 168\ cm$
Two-way roads: $Req.width = 108 \cdot 2 + 90 = 306\ cm$

In Section 3.2.2, the traffic directions according to the directives of the Arbowet are already shown. However, the proposed routes for a milkrun or AGV system according to these directives are not yet determined. For an AGV this is the same as for a forklift; the shortest route is used for delivering the material and again the shortest route is used to return to the warehouse. This can easily be determined, as AGVs carry one material at a time and all new orders are picked at the warehouse. For a milkrun however, an efficient route has to be determined. This can be done using the Chinese Postman Problem (CPP), which is an optimization algorithm for determining the shortest route when all roads have to be travelled at least once.

4.1.2 Chinese Postman Problem

The CPP is a method that converts the layout of the production plant to a graph with nodes and edges. The nodes represent crossings on which traffic switches to other roads. The edges represent the roads and connect the nodes. Each edge has a weight that represents the distance. The graph is made Eulerian, which means that every node has an even number of edges. This is done in such a way that minimum weight is added. Next, the minimum distance is calculated to travel from a certain point and return to that point, while travelling along all edges (Eiselt et al., 1995). Next, a route can be determined that has a total distance of the value calculated.

Figure 14 shows a numerical example of the CPP. On the right, the red edges are added to make the graph Eulerian. The start/return point is the left-most node, and the minimum distance is:

$$Min. distance = 2 \cdot 2 + 4 + 4 + 3 + 7 + 4 + 4 + 2 \cdot 2 = 34$$
$$Shortest\ route = A - E - C - A - B - D - E - A = 34$$

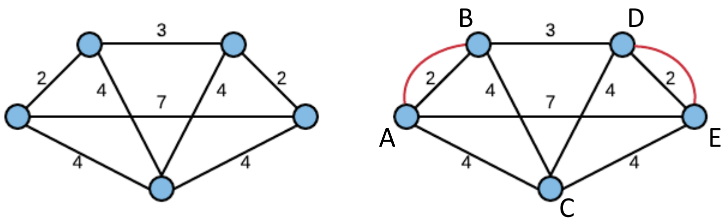

Figure 14: Chinese Postman Problem Example

In Chapter 5, the CPP is used to determine an efficient route for the BV milkrun system.

4.2 Organization of the Process

Solution methods for different aspects of organizing the BV logistics are found. Each paragraphs below explains the information found on a specific aspect.

At the moment, the SV milkrun driver scans the Kanban cards for materials that are waiting to be replenished. Research is done on the possibilities to eliminate the waiting time. This means that the material is directly scanned when the material is empty, so in that case the SV milkrun driver will not scan the cards anymore. Of course, the scanning can be done by a production worker instead of the SV milkrun driver. Then, the production worker scans the card instead of placing it in the collection box. However, literature shows that this could be automated. For example, sensors can be placed at the locations of materials, such that a signal is automatically send to the warehouse that a material needs to be replenished (Werma Signaltechnik, 2019). This eliminates the waiting time and possible human failures. Therefore, the performance could improve.

Literature also shows that prioritizing orders can improve the service level, as critical orders can be replenished first instead of the FCFS principle (Werma Signaltechnik, 2019). To verify this, the company Zehnder Group Zwolle is visited. The company visit confirmed that prioritizing critical orders can be of use if short replenishment times are required. It can be done automatically, which requires more effort during the implementation of the prioritization, or it can be done by hand if a clear priority rule is easily observable by the employees in the warehouse. During the company visit, it is also observed that using a time schedule could be a good way of organising the process if more than one material is transported at the same time by the same vehicle. Although it can sometimes create waiting time for the driver and therefore longer replenishment times, it reduces traffic congestion and driving inefficiently with e.g. one material at a time.

According to literature, various choices can be made on using dedicated or generic routes for delivering materials, since different combinations of both are possible. Dedicated routes for replenishment are often used when a consistent need is required for all routes, while generic routes are often used when transporters cannot carry a relatively high number of materials at a time (Fleischmann & Klose, 2005). During a simulation study, different strategies can be simulated if this is required.

4.3 Material Handling Options for the Process

During the BV logistics, material is handled at several moments. Materials are picked in the warehouse, materials are transported to the production area and finally the materials are placed in the allocated location at a production line. First of all, the options of picking BV materials are described after which several possibilities for delivering the BV materials are proposed, concerning the implementation an AGV or milkrun system.

4.3.1 Picking Materials

The options for picking the materials in the BV warehouse are limited. As described in Section 2.1.2 materials are picked from high storage racks, which means that equipment is needed that can pick from heights. However, fully automated systems are not applicable since the packaging has to be opened and removed, which is not the same for all materials. Therefore, the use of an employee is required for the picking process. As the current way of picking is already done with a forklift, more innovative or partially automated possibilities for picking are analysed.

Order picking systems are divided into two categories. These categories are in-the-aisle order picking systems and end-of-aisle order picking systems (Tompkins, White, Bozer, & Tanchoco, 2010). In-the-aisle means that the picker travels to the location where the material is to be picked. End-of-aisle means that a material is brought to the picker automatically. The latter is done by an Automated Storage/Retrieval System (AS/RS).

In the current situation, the in-the-aisle principle is performed. As the materials are too heavy and stored away at height, the picker uses a forklift to pick materials. Therefore, in this section the focus is on the end-of-aisle order picking systems.

Several end-of-aisle order picking systems exist. Most of the systems use a Chebyshev metric principle. Chebyshev metric means that the centres of the pick locations have an equal distance between one another in the width and an equal distance in the height. When bringing the materials to the picker is done according to a Chebyshev metric principle and the paths are rectangular, the principle of the different picking systems is the same (Tompkins, White, Bozer, & Tanchoco, 2010). This is the case in the BV warehouse in the production plant. A picker can communicate with the AS/RS by pressing a button that a certain material is needed. Next, the system gets the material required and brings it to the pick location where the picker is waiting for the material. Finally, the picker picks the material and gives the system a signal that the pick is completed. The system finished its task and waits for the next signal to pick an order.

4.3.2 Delivering Materials

As this research concerns the implementation of an AGV or milkrun system, the proposed options for transporting and placing materials in the production lines include different types of transport equipment.

Searching for milkrun and AGV options, roughly two system types were found for both the milkrun and the AGV system that are suitable for the production plant of Bosch Thermotechniek Deventer. Therefore, to the knowledge of this research, the following options exist:

- A milkrun with wagons that can carry trolleys with materials;
- A milkrun with plateaus that contain roller tracks, on which materials are loaded and unloaded.
- An AGV that carries a material on top of itself;
- An AGV that has forks on which a material can be placed.

Milkrun Train with Wagons for Trolleys with Pallets

An example of a milkrun train with trolleys is shown in Figure 15 (Still, 2018). This type of milkrun system uses trolleys on which BV materials are placed. When materials are placed on the trolleys, the trolleys can be pushed on the wagons and the delivery process starts.

Figure 15: Milkrun System with Trolleys

Such a milkrun system is a flexible system, since trolleys can be placed in any direction at the location in the production line. This creates opportunities for production lines where positioning both in the length and sideways is required, due to e.g. minimum available space. Also, materials can be loaded and unloaded from both sides of the train. This provides that all materials can be unloaded in the production area, even if a road is a one-way road and the locations for the materials are positioned at both sides.

Milkrun Train with Roller Tracks for Pallets

An example of a milkrun train with roller tracks is shown in Figure 16 (Still, 2018). BV Materials are placed on the roller system and are delivered at the production line by driving exactly next to the allocated location so the pallet can roll on its destination.

Figure 16: Milkrun System with Roller Tracks

For this type of milkrun system the materials have to be placed sideways during transportation, since the pallets have to be unloaded in the length. When using such a milkrun system, the materials can be loaded and unloaded manually or the roller tracks are driven by an electric motor. This is an ergonomic advantage, but in contrast to the milkrun system on trolleys, this system is not that flexible. This is due to the fact that the milkrun itself has to be placed exactly next to the location in the production line.

AGV that carries the Pallet on Top of Itself

An example of an AGV that carries the material on itself is shown in Figure 17 (Mobile Industrial Robots, 2019). This type of AGVs can pick a material from a pallet rack that fits the height of the AGV. Next, the AGV lifts the pallet in such a way that it can drive it out of the rack and transport it to the production area.

Figure 17: AGV that carries the Pallet on Top of Itself

The AGV system requires the production area to have the pallet locations equipped with pallet racks, such that the AGV can place the transported materials. For transporting a material, the AGVs need to be guided along the way to its destination. This can be done using various techniques (Warnecke, 1984):

- Fixed lines in or on the floor, such that the AGV can follow these lines;
- A coordinated system with on-board and off-board sensors that direct the AGV correctly;
- Sensors on the AGV which makes it autonomous, such that the destination is found on its own.

The guidance techniques with fixed lines use lines in or on the ground. These lines could be e.g. magnetic lines buried in the ground or painted lines on the ground. The advantage of these techniques is that the techniques are reliable and easy to implement, but on the contrary, they constrain the motion of the AGVs as the lines are fixed (Chun-Yi et al., 2012). Another issue concerning painted lines is that other traffic can damage the lines, which makes it less reliable over time. Considering the fact that routes could change, AGVs using the first guiding technique are not able to follow the new routes as long as there are no lines. The other two guidance techniques, a coordinated or autonomous system, can cope with flexible routes.

AGV that carries the Pallet on Forks

An example of an AGV that carries the load on forks is shown in Figure 18 (Toyota, 2019). These AGVs can pick materials from storage racks, as the forks can lift to heights. If materials are stored in the racks without any handling needed for e.g. packaging material, no employee is needed to pick materials from a high warehouse.

Figure 18: AGV that carries the Pallet on forks

No specific pallet racks are required in the production area for this type of AGVs, as the forks can place a material both on height and on the ground. However, this type of AGV is more complicated and more expensive as this AGV has more moving parts and is capable of more difficult material handling. The techniques used to let this type of AGV find its way to the destination are the same as the techniques used for the AGVs that carry the load on top of itself.

4.4 Conclusion

Insights are found on different aspects of the BV process. Possible solution methods are found for both picking and transporting materials.

The safety regulations for traffic conclude that several roads have to be changed from two-way to one-way. Which roads have to be changed is already explained in Section 3.2.2. With this information, the CPP is used to determine an efficient route for the BV milkrun to follow, when delivering materials.

Several options are found for the organization of the BV process, which are implemented and analysed in the simulation study of the future situations described in Chapter 5. The improvement can be made that production workers scan the Kanban cards, such that waiting time of orders is reduced. Orders can be prioritized in order to provide a more robust replenishment system, since orders with a short replenishment time can be transported first. As the milkruns transport more than one material at a time and perform a predefined route through the production area, the implementation of a time schedule can reduce traffic congestion and thus influence the performance. Furthermore, dedicated or generic routes could be used.

For both the milkrun and AGV system, two options are found in literature. For the milkrun system, the options are: a milkrun with wagons that carries trolleys with materials, or a milkrun with roller plateaus on which materials are directly placed. The milkrun with trolleys is more flexible for tight production areas, while the milkrun with roller plateaus can unload materials automatically. For the AGVs, the options are: an AGV that carries the material on top of itself, or an AGV with forks on which a material can be placed. The AGVs that carry a load on forks are capable of more material handling than AGVs that carry a load on top of. However, the investment is also higher.

The next chapter responds to this literature review, as the possible options are analysed and discussed for implementation in practice and in the simulation study.

Chapter 5 – Improvement Analysis

The performance is analysed for multiple proposed future situations by performing a simulation study that is comparable with the simulation study of the current situation. Changes are made to the DES model of the current situation to make sure the model represents the future situations in practice well. Again, the simulation study is based on the design of the BV process and the production planning of 2018. After the design of the process, experiments are performed to simulate the behaviour of the system. With the results, this chapter provides answers to the following sub questions of the research:

9 What are the technical requirements for the milkrun process and for the AGV process?

10 What is an efficient route design for a milkrun process and for an AGV system?

11 What capacity is required in the new process, by taking into account fluctuations in demand?

12 Which logistic system should be used, in terms of the performance and the ROI?

Question nine is answered by discussing the technical limitations in the production plant with employees and by using the possibilities for a milkrun or AGV system, shown in literature. To give an answer on question ten, the Chinese Postman Problem (CPP) is performed, which is found in Chapter 4. Question eleven is answered by executing the simulation studies for both the milkrun and AGV systems. Certain parameters and distributions are changed for the new DES models, which are collected by observations and external interviews. Question twelve is answered by analysing the results of the simulation study.

In Section 5.1 the simulation study for the milkrun system is explained. At first, the technical requirements are described. Next, the adjustments to the DES model together with the new experimental design are explained. Section 5.2 contains the same structure, but this section is dedicated to the AGV system. Finally, a conclusion is made in Section 5.3.

5.1 Milkrun System for Big Volume Logistics

The possibilities for the BV milkrun process are analysed to get insight in the requirements and limitations of the process when used in practice. After gathering this information, the DES model is modified according to these requirements and limitations. Finally, experiments are performed with this new DES model.

5.1.1 Requirements in Practice

Several meetings and discussions are held with production and logistic employees to analyse what requirements and limitations exist in the production plant. The possibilities found in the literature review are also discussed to see whether the options are in line with the requirements and limitations. This sub section explains the requirements and limitations that are found.

The BV Milkrun System

In Chapter 4, two different milkrun systems are found. One is a milkrun system with wagons for carrying trolleys and the other has plateaus with a roller system on which materials are directly placed. The milkrun using wagons and trolleys is more suitable than the system that has plateaus with rollers.

This is because of the flexibility that is required due to limited space in the production area. A significant number of locations for BV materials is positioned at the corners of a production line. The driver of a milkrun with roller systems has to drive around the corner and has to position one of the wagons right next to the destination of the material, such that it can roll on its destination. Sometimes, the driver cannot see the wagon at that angle, which makes it impossible to exactly perform this move. Therefore, a milkrun with wagons and trolleys is the desired milkrun system.

Picking Materials

As already mentioned, an employee is needed for picking materials in the warehouse, since a milkrun cannot pick materials from locations at height. The workload of that employee would be inefficient if materials are picked automatically and the employee only have to remove or cut open packaging material. Therefore, the employee picks materials, removes or cuts open packaging material when needed, and prepares the trolleys for loading on the milkrun train.

When a milkrun driver returns in the warehouse from delivering materials to the production lines, new trolleys with materials have to be placed on the milkrun train. The picker has prepared the trolleys, so materials are waiting to be transported. The milkrun driver and the picker unload and load the milkrun train together, such that this process is as fast as possible. Next, the milkrun driver transports the materials and the picker picks the next orders.

Including Packaging Material on Return

In the production area, the materials are placed by a two bin principle. That is, two pallets with materials behind or next to each other. When a pallet is empty, the trolleys are switched from position. Next, an order is placed for the BV warehouse and the BV milkrun driver delivers a new trolley with materials. Since the trolley with the empty pallet is still at that position, the new trolley with materials is switched with the empty one. Therefore, the milkrun driver takes the trolley with the empty pallet with him on the way back to deliver it at the repack department. As this is the case, the packaging material that is left after all materials are used, is also placed on the empty pallet. This is also delivered at the repack department.

Because of the fact that the BV milkrun needs to stop at the repack department, there are also empty trolleys in a buffer system, such that the trolleys with pallets and packaging material can be switched with empty trolleys. By doing this, the BV milkrun can proceed with its cycle and arrives in the warehouse with the empty trolleys. There, the unloading and loading process is performed as described in the previous sub section, such that the BV milkrun can deliver the next orders.

BV Milkrun Route

As mentioned in Section 4.1, the CPP is used to determine the most efficient route for the BV milkrun to travel along all roads. One generic route is determined for the entire production area, as there is not enough space in the BV warehouse to prepare trolleys for more than one milkrun at a time. Besides that, the frequency of several materials is so low (once in a few hours) that a dedicated milkrun train for different production lines would be inefficient, because the milkrun would not be full all the time.

Figure 19 shows the Eulerian graph at the left, in which all nodes have an even number of edges. The minimum distance to travel all roads is determined for the case that all roads could be used both ways. Next, a route is determined by following the allowed traffic directions and by using common sense. As this route has the minimum distance, the traffic rules do not have an influence on the distance of the route and the shortest route is found. The route is visualized at the right side of the figure. The minimum distance and the shortest route are calculated as follows:

$$Min.\,distance = 7 + 2 \cdot 9 + 10 + 10 + 44 + 17 + 2 \cdot 18 + 46 + 2 \cdot 26 + 29 + 29 + 49 = 347$$
$$Shortest\ route = A - B - C - D - E - B - C - H - G - I - H - G - F - H - I - A = 347$$

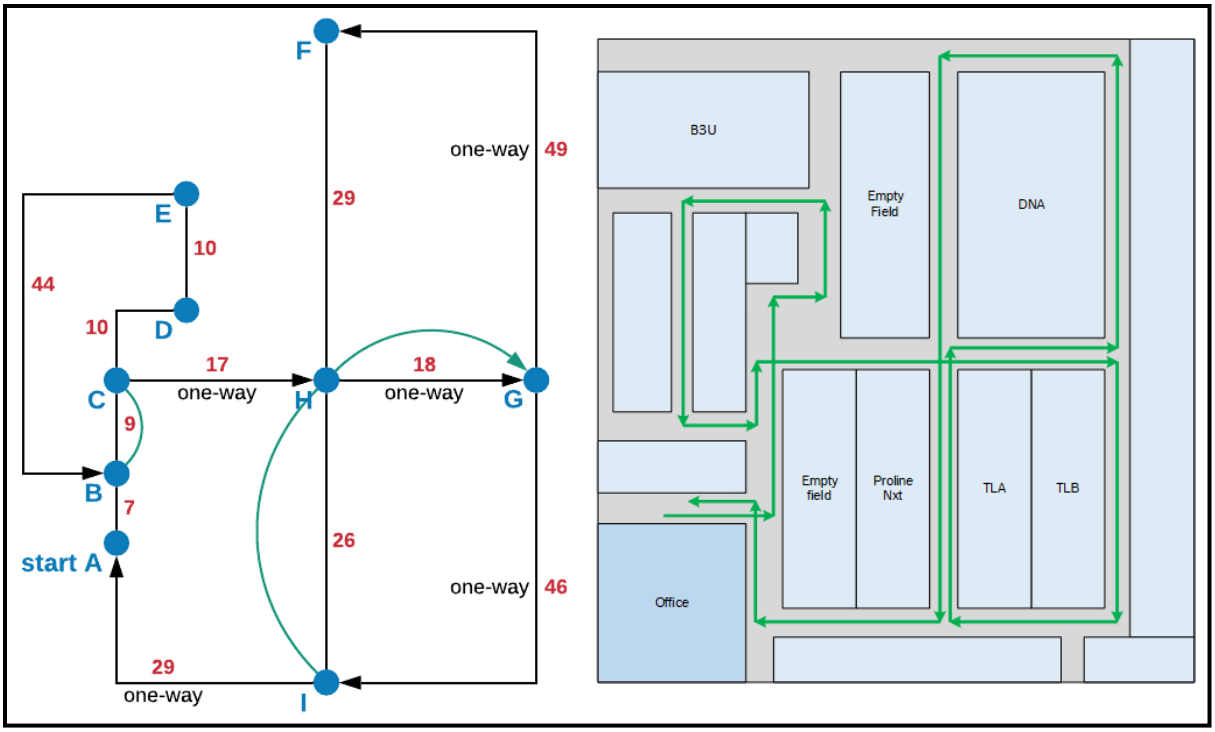

Figure 19: Chinese Postman Problem - BV Milkrun

Process Flowchart

The process flowchart of the BV milkrun system is shown in Figure 20. The rows represent the responsible person who carries out the process step, while the columns represent the location in the production plant where it is performed. Recall that the process flowchart of the current process is only the replenishment process, as the return of packaging material and pallets is a separate process and carried out by another employee. Since the BV milkrun system also transports packaging material and pallets on its way back to the warehouse, the process flowchart is more extensive than the process flowchart of the current situation with forklifts. The orange text boxes are additional or different, compared to the flowchart of the current process.

Unloading and loading the BV milkrun train is done by the BV picker and the BV milkrun driver together. Therefore, these process steps are double in the flowchart with both scenarios having a 50/50 percentage when considering the workload.

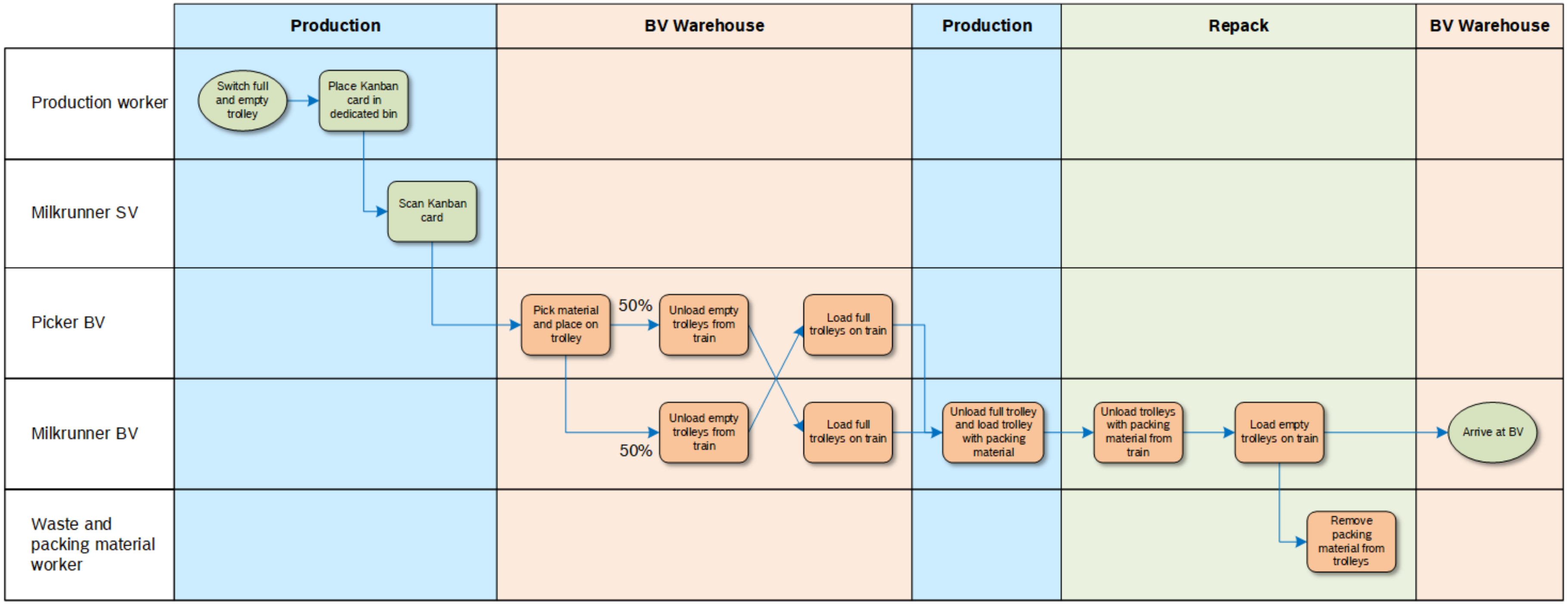

Figure 20: Visualization of the Future Milkrun Logistics

5.1.2 Big Volume Milkrun Simulation Study

The simulation study is in the basis the same DES model as the simulation study on the current situation. However, changes are made that are decisive for the performance of the model.

Adjustments to the Model

In order to simulate the BV milkrun process properly, adjustments are made to the DES model of the current situation. The following changes are made:

- The number of transporters together with picking in the warehouse;
- The route through the production area;
- The return of packaging material and empty pallets;
- The requirements for performing all experiments.

There is no switch between two or three transporters according to the workload. This is changed to a fixed number of transporters, but this fixed number varies between experiments. As mentioned in Section 3.1.2, considering the current situation, the DES model uses two transporters who also pick materials and a third dedicated picker is deployed when the workload is too high. In the latter case the other two transporters do not pick materials. With a milkrun system however, the transporters cannot pick the materials as the milkrun cannot pick at height. Therefore, a dedicated picker is always necessary in the warehouse. Furthermore, the number of materials carried per transporter also change per experiment as configurations of the milkruns change.

In the current situation, the forklifts use the shortest route to their destination and return to the warehouse after the material is delivered. As described in Section 5.1.1, the BV milkruns use a predefined route through the entire production area. Therefore the way of making decisions on crossings is changed. The BV milkruns also take empty pallets and packaging material with them from the production area to the repack area after a material is delivered. Therefore, the DES model also needs a stop at that specific place in order to simulate that event.

The simulated interventions and scenarios are explained in the next sub section. In order to be able to simulate these aspects by several experiments, adjustments are required to the model. One intervention for example is the use of a time schedule for the transporters. For this intervention, a code is required that let the transporters behave according to that time schedule. Every intervention and scenario has its own piece of required code.

In the same way as done in Section 3.2.1, the number of runs and the warmup period are determined. The number of runs are calculated by determining the mean of an output variable with a specified confidence. The warmup period is determined by Welch's graphical procedure. The same values are found as the values used for the current situation. Four runs are performed with a warmup period of one day.

Experiments Performed

For the BV milkrun system, several experiments are performed. Interventions are done to test several settings for the BV logistics, and scenarios are simulated to see how the same settings behave under different circumstances. An overview of the interventions and an overview of the scenarios for the experiments is shown in Table 9 and Table 10, respectively. Reasoning for the choice of the different interventions and scenarios is explained.

Intervention	Range	Description
Number of transporters	1 - 3	The number of transporters used to transport materials, without the one picking materials in the warehouse.
Number of wagons per transporter	1 - 4	The number of wagons each milkrun contains.
Perform full route	True/False	If true: the milkrun always drives the complete tour through the production area. If false: the milkrun returns to the warehouse if all materials are delivered.
Prioritize orders in warehouse	True/False	If true: the orders are prioritized before placing the materials on the trolleys. If false: the orders are placed on the trolleys by a first come first served principle.
Use a time schedule for transporters	True/False	If true: the milkruns are performing routes through the production area by using a time schedule. If false: the milkruns do not have to wait for a scheduled time to performthe next route.

Table 9: Interventions for the BV Milkrun Experiments

The number of transporters and the number of wagons per transporter are variables for determining the capacity required for the BV logistics. The other three interventions are different strategies for the logistics, which have an influence on the required capacity. The interventions for performing a full route and using a time schedule are used to see what the best regulations are for the logistics in terms of traffic regulation. Prioritizing orders in the warehouse is an intervention that increases the performance in terms of required replenishment times, as the required replenishment times are material-specific and therefore certain orders are more critical than others.

Besides the interventions, several scenarios are simulated. These scenarios are shown in Table 10. Recall that orders are waiting in the production area for the SV milkrun driver to drive past and scan the order. Since the SV milkrun drives through the production area according to a time schedule with fixed intervals, the order can be waiting for a random period of time between 0 and this fixed interval. Over a year, the expectation is that the duration of that waiting time varies per order. Therefore, the first scenario simulates the situation with the expected performance. However, it could be that orders are waiting longer than expected, since there simply is no data to make a clear conclusion on this. The second scenario covers this situation, because in that scenario all orders are waiting in the production area the longest time possible.

The third scenario is simulated to analyse what the effect would be when the orders do not have to wait in the production area. In fact, in this case the orders are directly scanned when a pallet with material is empty. This means that the SV milkrun driver does not have to scan the orders, but that production workers scan the orders.

Scenario	Description
Expected performance	A new order is waiting in the production area to be scanned by a SV milkrun driver. The expected waiting time is a random value between 0 and the maximum number of minutes that it can take before a SV milkrun drives by, according to their time schedule.
Worst case performance	In the worst case scenario, the orders are always waiting the maximum time that is possible according to the SV milkrun time schedule.
Best case performance	In the best case scenario, the orders are not waiting in the production area. This scenario simulates the behaviour of the system when the orders are directly scanned at the production line.

Table 10: Scenarios for the BV Milkrun Experiments

The experiments are performed according to a full factorial design. This means that all possible combinations of interventions and scenarios are simulated. In this way, a complete overview of the performance per combination can be analysed.

All interventions together create 96 combinations, which are 96 experiments to simulate. Combining this with the scenarios means that the 96 experiments have to be simulated under three different scenarios. This gives a total of 288 experiments with each four runs of an entire production year. As the average computation time of an experiment is around two minutes, the total simulation time is over nine hours.

To cope with this long computation time, preliminary experiments are performed with one run instead of four in order to analyse which experiments are useful in practice according to the performance. Of course, the random variables have an influence, as four runs are required due to the randomness. However, experiments that for example only have delivered *(confidential)* out of *(confidential)* orders within the replenishment time, will also not perform well when the variables are changed with Common Random Numbers (CRNs).

Figure 21 shows the performance of the preliminary experiments with the scenario that represents the expected situation. As can be seen in the figure, experiments 1 - 44 have a bad performance. Not even 75% of the orders in those experiments is delivered on time. The same holds for experiments 65 - 68. Experiments 58 and 60 also are in the same situation, but for these two experiments only one strategic intervention has a different value compared to the experiments around itself. Therefore, these experiments are further analysed, together with the experiments that perform relatively well. In total, 48 experiments are further analysed.

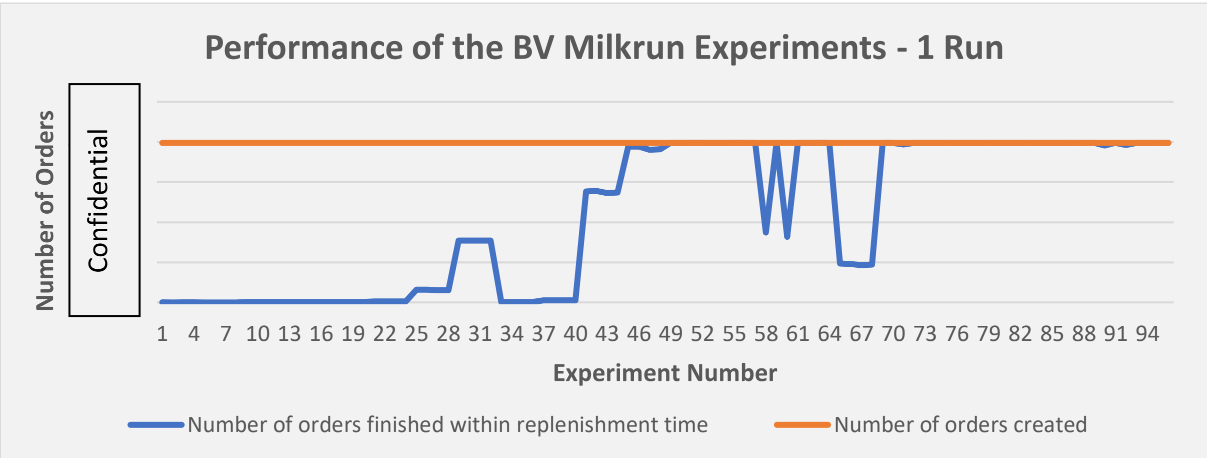

Figure 21: Performance of the BV Milkrun Experiments – 1 Run

For the experiments that are further analysed, the experiments are performed with four runs. The performance of these experiments is shown in Figure 22. Experiments 14 and 16 are the same experiments as the numbers 58 and 60 in the preliminary experiments. Recall that the threshold for the service level is 99%. One can see that experiments 14 and 16 have a bad performance. Experiments 1 - 4 also show a performance that is worse than the rest of the experiments, because around *(confidential)* orders are delivered too late. Therefore, these six experiments are left out of consideration. Further details on the results of the experiments that perform well, are shown in Table 11.

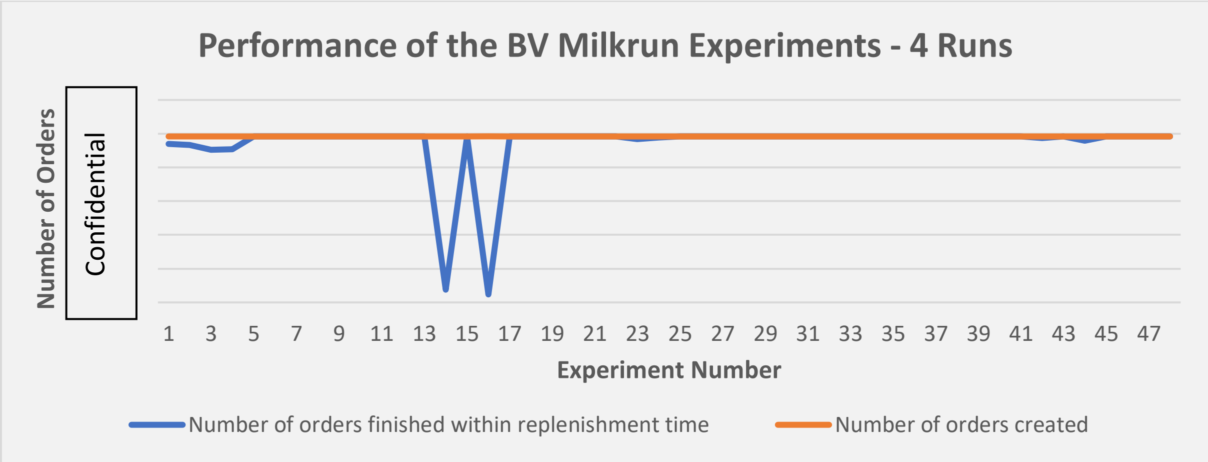

Figure 22: Performance of the BV Milkrun Experiments – 4 Runs

Results of the Experiments

Table 11 shows the results of the experiments in the situation that two transporters carry out the process. The complete table with all 48 experiments is shown in Appendix C. As one can see in the table, the service level of the experiments is above the threshold of 99%. The performance of some experiments is even better than the current performance, since the service level is higher than the current situation. In the current situation the service level is 99.957%. Since the service levels are that high, it is not necessary to increase the capacity to three transporters as this would only rise the yearly costs of the process. In the same way as the current situation, the yearly process costs account for labour costs and equipment costs. Lease prices are estimated for the milkruns, since the entire fleet of vehicles within the plant are leased. The investments cover the trolleys.

Simulation study						Avg. replenish time	Total number of orders	Orders within replenish time	Orders too late per year	Yearly costs of process	Investment costs	Production loss per year	Service level [%]
ExpNo	Transp	Wagons	FullTour	Prioritise	Schedule	[min]							
5	2	3	TRUE	TRUE	TRUE	20.04							99.997
6	2	3	TRUE	TRUE	FALSE	20.34							99.997
7	2	3	TRUE	FALSE	TRUE	20.04							99.965
8	2	3	TRUE	FALSE	FALSE	20.27							99.909
9	2	3	FALSE	TRUE	TRUE	20.02							99.997
10	2	3	FALSE	TRUE	FALSE	17.38							99.997
11	2	3	FALSE	FALSE	TRUE	20.02							99.967
12	2	3	FALSE	FALSE	FALSE	17.42				Confidential			99.992
13	2	4	TRUE	TRUE	TRUE	21.85							99.997
15	2	4	TRUE	FALSE	TRUE	21.85							99.919
17	2	4	FALSE	TRUE	TRUE	21.84							99.997
18	2	4	FALSE	TRUE	FALSE	17.58							99.995
19	2	4	FALSE	FALSE	TRUE	21.84							99.922
20	2	4	FALSE	FALSE	FALSE	17.58							99.985

Table 11: Detailed Results of the BV Milkrun Experiments – Expected Scenario

Until now, the experiments are scored on quantitative performance. However, qualitative performance in terms of the perspective of an employee is of importance as well. Employees should be able to work with a clear working package, so they do not have the feeling that they have to rush. To take this into account, the results of the simulation study are discussed with several employees, who carry out the current BV logistics. This discussion concluded the following:

- Returning to the warehouse when all materials are delivered has approximately the same performance as always performing a complete tour through the production area. For traffic convenience, it is better to return to the warehouse and wait for the next job.

- To get a well-organised and structured process for the BV logistics, it is important to use a time schedule. This is convenient for the employees, as the drivers know exactly when they have to start and when they can wait.
- When looking at the performance of the experiments with a time schedule and with returning to the warehouse when the milkrun is empty, prioritising orders has a higher service level. When looking at the overall table, experiments with the orders prioritised all perform better than the experiments that do not prioritise them. Therefore, prioritising orders is a good intervention.

The robustness is checked for the experiments that not only perform well according to the quantitative requirements, but also are in line with the qualitative conclusions. This is done by considering the worst case scenario. As explained, in the worst case scenario all orders are waiting in the collection boxes at the production lines, for the longest time possible. The performance of the experiments is shown in Table 12.

Simulation study						Avg. replenish time [min]	Total number of orders	Orders within replenish time	Orders too late per year (worst case)	Yearly costs of process	Investment costs	Production loss per year	Service level [%]
ExpNo	Transp	Wagons	FullTour	Prioritise	Schedule								
9	2	3	FALSE	TRUE	TRUE	26.15	Confidential						99.997
17	2	4	FALSE	TRUE	TRUE	27.97							99.995

Table 12: Detailed Results of the BV Milkrun Experiments – Worst Case Scenario

One can see that both experiments still perform well. The service level is still above the threshold of 99% and higher than the current situation. Besides the service level, when looking at the average replenishment time and the yearly costs, experiment 9 performs better. Therefore, this setting is the chosen setting if a BV milkrun is the chosen system for the BV logistics. In the next section, the performance of the AGV system is analysed, such that the systems can be compared.

5.2 AGV System for Big Volume Logistics

In the same way as done for the BV milkrun process, the possibilities for the AGV process are analysed to get insight in the requirements and limitations of the process when used in practice. The DES model is modified according to the requirements and limitations and again, experiments are performed.

5.2.1 Requirements in Practice

Discussions are held with employees to analyse the requirements and limitations in the production plant for the implementation of AGVs. The options found in the literature review are discussed to see which option is the best in line with the requirements and limitations in practice. This sub section explains the requirements and limitations that are found.

Picking Materials

As mentioned, a picker is needed in the warehouse to cut open or remove packaging. As explained in Section 5.1.1, the workload of the picker would be inefficient if materials are automatically picked and the employee only has to cut open or remove packaging. Therefore, the same conclusion as for the BV milkrun system can be made. An employee picks materials, removes or cuts open packaging when needed, and places the material on a pallet rack. Next, an AGV can pick up the pallet that is ready to be transported to the production line.

The BV AGV System

Since the AGV does not have to pick the materials from the storage racks, it is not needed to deploy an AGV that can pick materials from heights. Such an AGV system is more complex than an AGV that only carries the materials. Therefore, the relatively simple AGVs that can carry a load on top of itself, is the desired AGV system.

Packaging Material separate Process

In the production area, the materials are placed behind or next to each other. Materials that are behind each other cannot be switched, since the materials are not on trolleys like they are when the BV milkrun process would be implemented. Therefore, the AGV cannot reach the empty pallet and remove it together with the packaging material. Besides that, the AGV already carries a full pallet that first has to be placed, before an empty pallet could be picked. Due to this, the removal of packaging material and empty pallets is not included in the AGV system. This will be a separate process, just like it is in the current situation.

BV AGV Routes

The AGVs carry one material at a time and always have to return to the warehouse for a new job. Therefore, complex routing is not desired, as an AGV can be directed along the shortest route for delivering the material and again the shortest route for returning to the warehouse.

Process Flowchart

The process flowchart of the AGV system is shown in Figure 23. The orange text boxes are additional or changed operations, compared to the flowchart of the current situation. The AGV flowchart is a little more extensive than the flowchart of the current process, since the material is not picked and transported by the same employee. The picker places the material on a pallet rack, such that the AGV can transport it to the destination. The flowchart is not as extensive as the BV milkrun process, as the removal of packaging material and empty pallets is a separate process.

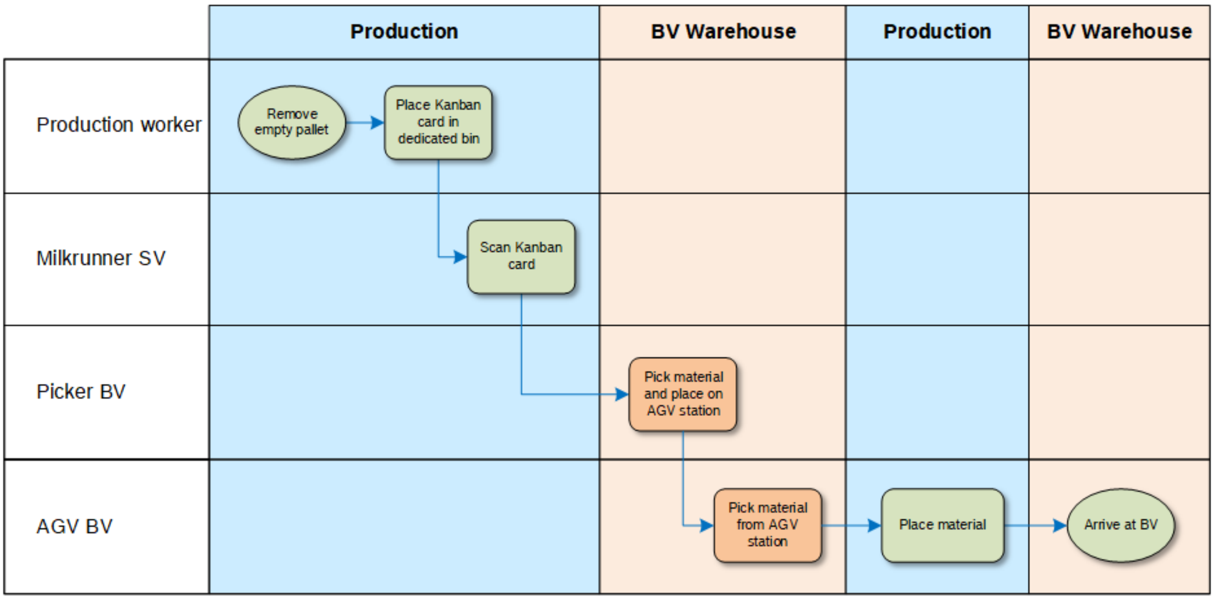

Figure 23: Visualization of the Future AGV Logistics

5.2.2 Big Volume AGV Simulation Study

The simulation study is in the basis the same DES model as the simulation study of the current situation. Again, changes are made that have a high influence on the performance of the model.

Adjustments to the Model

In order to simulate the BV AGV process properly, adjustments are made to the DES model of the current situation. The AGV process requires changes for the same type of aspects, only this time the changes are implemented slightly different and besides that, less changes to the current situation have to be made. The following changes are made:

- The number of transporters together with picking in the warehouse;
- The requirements for performing all experiments.

As mentioned in Section 3.1.2, the DES model of the current situation uses two transporters who also pick materials and a third dedicated picker is used when the workload is too high. In the latter case the other two transporters do not pick materials. With an AGV system however, the transporters cannot pick the materials as the AGVs cannot pick at height. Therefore, a dedicated picker is always necessary in the warehouse. The rest of the process for delivering materials to the production line, is programmed in the same way as for the forklifts in the current situation.

In the same way as done for the BV milkrun process, the simulated interventions and scenarios are explained in the next sub section. In order to be able to simulate these aspects by several experiments, adjustments are required to the model. Again, a piece of code is implemented for every intervention and scenario.

Again, the number of runs and the warmup period are determined. The number of runs are calculated by determining the mean of an output variable with a specified confidence. The warmup period is determined by Welch's graphical procedure. The same values are found as the values used for the other situations. Four runs are performed per experiment and a warmup period of one day is used.

Experiments Performed

Interventions are done to test several settings for the process, and scenarios are simulated to see how these settings behave under different circumstances. An overview of the interventions and an overview of the scenarios is shown in Table 13 and Table 14, respectively. The interventions and scenarios are the same as the ones used for simulating the BV milkrun system. In the case of AGVs however, the interventions are limited to the number of transporters and prioritizing the orders. This is because of the fact that AGVs carry one material at a time and therefore do not have to be guided by a time schedule. Also the routing of AGVs is easier, since orders always have to be picked at the warehouse and the shortest route to the destination and back is needed for delivering the materials.

The number of AGVs is an intervention to determine the capacity required for the process, while prioritizing the orders is a strategy that can have an influence on the required capacity.

Intervention	Range	Description
Number of transporters	1 - 3	The number of transporters used to transport materials, without the one picking materials in the warehouse.
Prioritize orders in warehouse	True/False	If true: the orders are prioritized before placing the materials on the trolleys. If false: the orders are placed on the trolleys by a first come first served principle.

Table 13: Interventions for the AGV Experiments

In the scenario for the expected performance, the waiting time or BV orders in the production area varies. In the worst case scenario, this time set to the maximum time possible. Finally, the best case shows the performance that orders are directly sent to the warehouse, without waiting in the production area.

Scenario	Description
Expected performance	A new order is waiting in the production area to be scanned by a SV milkrun driver. The expected waiting time is a random value between 0 and the maximum number of minutes that it can take before a SV milkrun drives by, according to their time schedule.
Worst case performance	In the worst case scenario, the orders are always waiting the maximum time that is possible according to the SV milkrun time schedule.
Best case performance	In the best case scenario, the orders are not waiting in the production area. This scenario simulates the behaviour of the system when the orders are directly scanned at the production line.

Table 14: Scenarios for the AGV Experiments

In the same way as done for the BV milkrun process, the experiments are performed according to a full factorial design, which means that every possible combination is analysed. The interventions create 6 combinations, which means that 6 experiments are performed. Combining this with the scenarios gives 18 experiments to simulate. As the average computation time of an experiment is around two minutes, the total simulation time is under 40 minutes. Therefore, all experiments are fully simulated with four runs.

Figure 24 shows the visualised performance of the experiment with the scenario of the expected performance. Experiments 1 and 2 show a bad performance. In these two experiments, one AGV is deployed. Thus, the conclusion can be made that one AGV is not enough for the BV logistics, which means that this is left out of consideration.

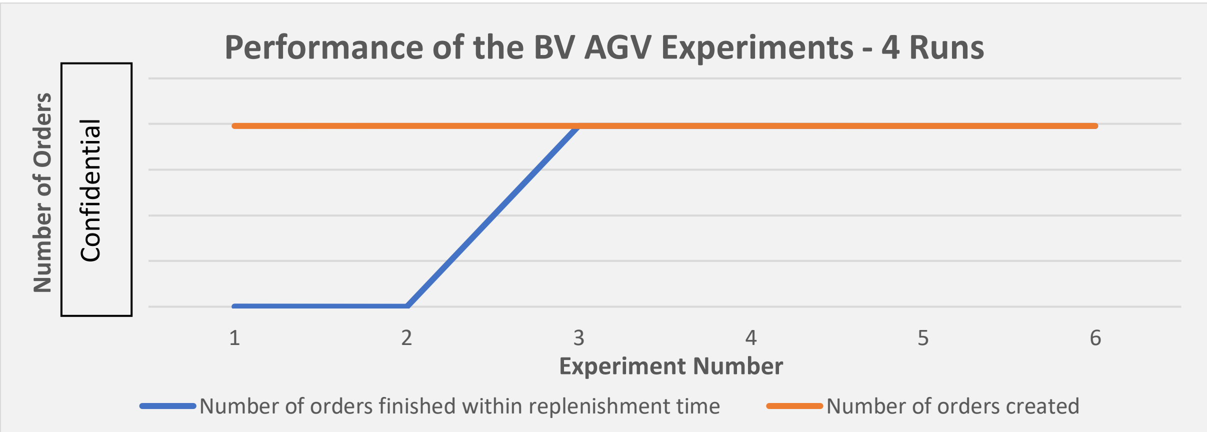

Figure 24: Performance of the BV AGV Experiments - 4 Runs

Results of the Experiments

The results of experiments 3 - 6 are shown in Table 15. The service level of the experiments is above the threshold of 99%. Recall that the current situation has a service level of 99.957%, which means that the performance of the AGVs is even better than the current performance. As two AGVs can handle the workload, a third AGV is not needed for only this process. This would only make the yearly process costs a lot higher as it rises linear with the number of AGVs deployed. Again, lease prices are estimated for calculating the yearly equipment costs, which is a part of the yearly process costs.

The experiments are examined on quantitative performance. For the AGV system, no qualitative performance is examined as done by the milkrun system, since the transporters can be programmed to the behaviour that is desired.

Simulation study			Avg. replenish time [min]	Total number of orders	Orders within replenish time	Orders too late per year	Yearly costs of process	Investment costs	Production loss per year	Service level [%]
ExpNo	Transp	Prioritise								
3	2	TRUE	13.61	Confidential						100.000
4	2	FALSE	13.61							100.000
5	3	TRUE	11.18							100.000
6	3	FALSE	11.17							100.000

Table 15: Detailed Results of the AGV Experiments – Expected Scenario

Again, for analysing the robustness, the experiments are checked in the worst case scenario. In that scenario all orders are waiting in the production area for the longest time possible. The worst case performance of the experiments is shown in Table 16. The service levels are still higher than the current situation and the levels are above the threshold of 99%.

Simulation study			Avg. replenish time [min]	Total number of orders	Orders within replenish time	Orders too late per year (worst case)	Yearly costs of process	Investment costs	Production loss per year	Service level [%]
ExpNo	Transp	Prioritise								
3	2	TRUE	19.74	Confidential						100.000
4	2	FALSE	19.74							99.997
5	3	TRUE	17.30							100.000
6	3	FALSE	17.30							100.000

Table 16: Detailed Results of the AGV Experiments – Worst Case Scenario

Prioritizing orders can be done by hand if simple rules are applied for considering a critical order. Therefore, experiment 3 is the chosen setting if the AGV system is chosen for the BV logistics. In that case, two AGVs are deployed and orders are prioritized in the warehouse. In the next section, the performance of the AGV and milkrun systems are compared and a final choice is made on the setting to implement.

5.3 Conclusion

The analysis of the BV milkrun system shows that the most suitable system is the milkrun with wagons on which trolleys with materials are transported. This is due to the flexibility that is required in the production area to place materials exactly on the specified location. A dedicated picker prepares the trolleys with materials such that the milkrun driver can deliver the materials. The milkrun driver switches the full trolley and the trolley with packaging material in the production area, and delivers the packaging material and pallets at the repack department before getting back to the warehouse. Two milkruns are deployed with each three wagons. For the process, several strategies are used. The first strategy is that the milkruns drive through the production area according to a fixed route and abort the route when the last material is delivered. Second, orders are prioritized in the warehouse, such that critical orders are delivered earlier. A third strategy is that the milkruns drive according to a time schedule. This makes sure that the two milkruns do not drive directly after each other, which otherwise would cause traffic congestion.

Next, the analysis of the BV AGV system shows that the AGVs carrying materials on top of themselves, are able to perform all required operations in the process. This is due to the fact that a picker is needed in the warehouse. More complex AGVs are therefore not desired, as these AGVs are more expensive and do not have an extra advantage for the process. Two AGVs are required for the supply of BV materials to the production lines and orders are prioritized in the warehouse.

The performance of the different systems is shown in Table 17. The milkrun system requires the most process changes, as the return of packaging material and empty pallets is no longer a separate process. Including that process has an ergonomic advantage, as production workers do not have to handle empty pallets anymore.

Simulation study	Avg. replenish time [min]	Total number of orders	Orders within replenish time	Orders too late per year	Yearly costs of process	Investment costs	Production loss per year	Service level
Current Situation - Future Traffic Rules	17.6	Confidential						99.957%
Future Situation - Milkruns	20.0							99.997%
Future Situation - AGVs	13.6							100.000%

Table 17: Results of the Simulation Studies

Figure 25 visualises the costs stated in the table, over the first seven years. The figure shows that the milkrun system is the most expensive system for the process of the BV logistics. The money invested will not be earned back, since the yearly process costs are the highest. The implementation of the milkrun system costs *(confidential)* per year extra, compared to the current situation. The AGV system has the least yearly costs, which is *(confidential)* cheaper than the current situation. Including the investment, the ROI is slightly under six years. On average, a production worker has to handle three empty pallets a day. With that given, the ergonomic advantage of the milkrun system does not compensate a yearly costs difference of *(confidential)* compared to yearly costs of the AGV system.

Therefore, according to this study, the AGV system is the best way to efficiently replace the forklifts for the BV logistics. The average replenishment time is 13.6 minutes with a service level of 100%.

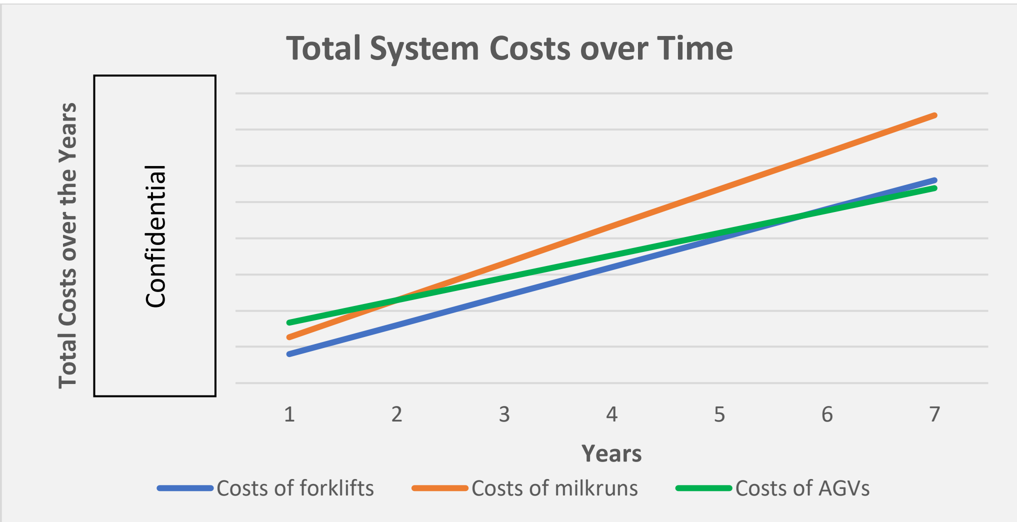

Figure 25: Return on Investment for both Systems

Chapter 6 – Discussion of the Simulation Study

Now that the complete simulation study has been discussed, the use of simulation as research method can be evaluated. Without discussing the results, the contribution of the simulation study is described.

This thesis has shown how a discrete event simulation model can be built, and how experiments can be performed and analysed during a simulation study with that model. This is done in context of the internal big volume transport logistics of Bosch Thermotechniek Deventer.

Chapter 1 explained the reasoning behind the choice to use a simulation study. A simulation study is useful if various settings are analysed and if the system has dynamic and stochastic properties in reality. This is the case, as unpredictable events like waiting and traffic congestion occur at different places. Therefore, using a simulation study was expected to be a suitable method. The results of the various settings provided detailed insights in several aspects of the system that were not known or expected. For example, the BV milkrun system: aborting the full route was expected to have a higher impact on the performance. The expectation was that less capacity is needed in terms of milkruns and/or wagons if the distance to drive is reduced. Furthermore, the average replenishment time was expected to reduce when deploying two AGVs with a dedicated picker instead of the current situation, but the difference was not expected to be that high. The stakeholders were surprised of these outcomes, which confirms that the simulation study was a useful method to analyse future situations.

The scientific contribution is more difficult to determine. The study is tailor-made for Bosch Thermotechniek Deventer. Nonetheless, the structure of building a discrete event simulation model, gathering data for parameters and variables, and performing several analyses with the simulation study, is a structure that shows how such a simulation study can be performed.

The assumptions made are continuously discussed with the problem owner and with the employees that work with the BV process, in order to make the assumptions as reliable as possible. The assumption did not restrict the simulation study too much, as a lot of aspects could still be analysed and various experiments have been performed for the future situation. The same holds for the interventions and scenarios, as the choices made are discussed with the stakeholders. The chosen interventions for performing experiments in the simulation study, e.g. prioritizing orders in the warehouse, are ways of regulating the process and therefore could directly be used when the new process is implemented. The scenarios also include possible solution methods that are suitable in the production plant. To conclude, performing a simulation study for this research was a good decision.

If Bosch wants to perform further research on future process changes, taking into account the results of this study, it is recommended to start with a research on including the return of pallets with packaging material in the working package of the AGVs. The required capacity has to be recalculated, as the workload for the AGVs becomes higher. However, the expectation is that still two AGVs are needed, since the workload of removing pallets with packaging materials is very low compared to the replenishment of materials. Furthermore, as the replenishment time of the materials with AGVs is significantly lower than the forklifts, and the forklifts have a performance that is good enough, there is room for the AGVs to extend the workload.

Now that the simulation study is finished, the next chapter describes what has to be done to implement the result of the simulation study.

Chapter 7 – Implementation of Improvement

Recall that the results of Chapter 5 show that AGVs are going to be implemented. In this chapter, the implementation of AGVs is analysed and an explanation is given for the different steps that have to be performed in order to implement the AGVs correctly. The different steps include physical changes in the production plant and adjustments to the organisation of the BV logistics. This chapter answers the following sub question of the research:

13 How should the system be implemented?

The sub question is answered by using the information obtained earlier during this research. Section 7.1 explains the changes in the BV logistics. Next, Section 7.2 shows the required physical changes to make the process work. The required adjustment in the SV milkrun process, due to the change of the BV logistics, is explained in Section 7.3.

7.1 Changes in the BV Logistics

Section 4.3 showed different control systems for coordinating AGVs. A flexible routing system is required for directing the AGVs, as Bosch is going to change the layout and position of a production line in a few years. Therefore, roads are changed and thus routes need to change as well. Furthermore, the exact locations of materials do change over time.

As mentioned in Section 5.3, orders are prioritized in the warehouse. Materials that have a low number of articles on the pallet should have priority, as these materials are the ones with a relatively short replenishment time. The exact number of articles for having priority should be determined and the Kanban system needs to print a priority mark on the Kanban card.

A pilot needs to be done with the AGVs in order to understand how they behave, before the system is implemented. Managing the behaviour of the AGVs and the interaction with other traffic can be monitored during the pilot. A pilot is advised, as the implementation of AGVs is a major investment.

7.2 Physical Changes in the Production Plant

The AGVs pick materials from and place materials on pallet racks. Therefore, the current BV locations in the production lines have to be broken down and replaced by the pallet racks. At the moment, some materials are placed directly on the floor. For these places, only pallet racks have to be placed. Other places however, have a roller system on the floor or on knee-height, which first has to be removed before the pallet racks could be placed.

Furthermore, pallet racks need to be placed in the BV warehouse on which the picker places the materials after the materials are picked from the storage racks. The AGVs can pick the prepared materials from the pallet racks to deliver them at the production lines.

7.3 Required Change in the SV Milkrun Process

When changing the BV logistics, the SV milkrun route has to be changed as well to follow the new traffic directions. Figure 26 shows the current and the new SV milkrun route at the left and right, respectively. By changing the SV milkrun route, it meets the future traffic rules and it does not interfere with the BV AGVs. The new SV milkrun route is determined by solving the CPP. The total distance is slightly reduced, and the milkrun does not have to turn back on the road at the bottom of the figure.

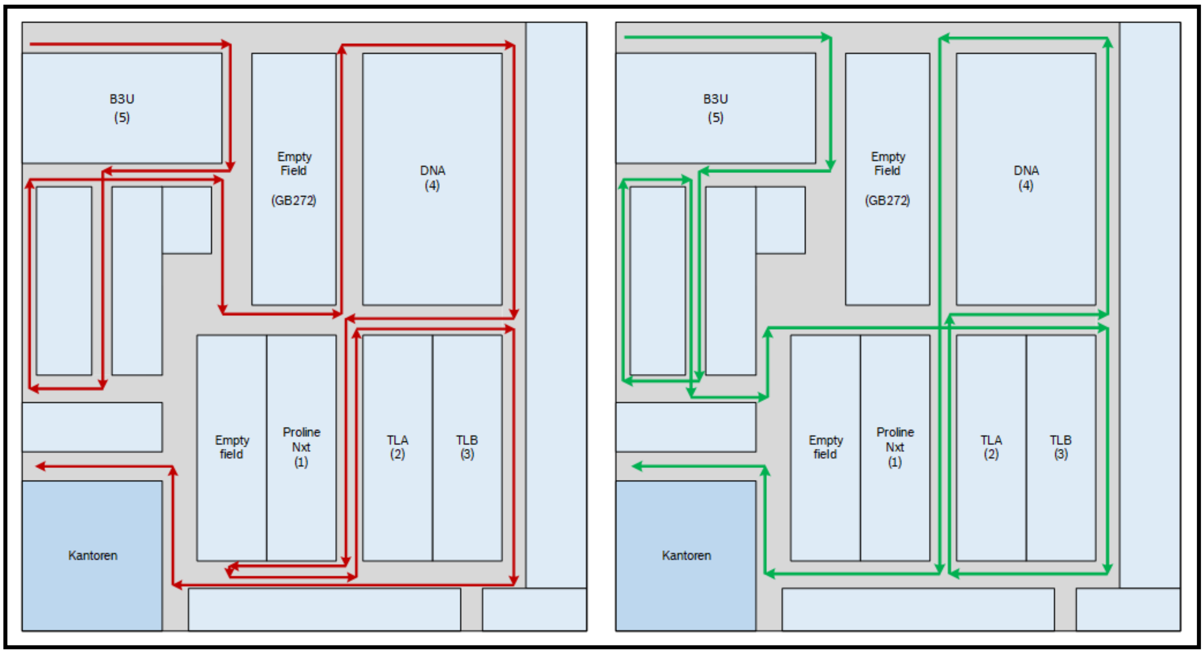

Figure 26: SV Milkrun Route – Current (left) and New (right)

Chapter 8 – Conclusions and Recommendations

In this chapter, the main conclusions of this study are discussed in Section 8.1. Furthermore, recommendations and topics for future research are explained in Section 8.2.

8.1 Conclusions

This research is performed to give an answer to the following research question:

"How should the logistic system for the big volume processes be designed to efficiently replace the forklifts in the production environment at Bosch Thermotechniek Deventer? Specifically, which option will be more efficient; a milkrun system or an automated guided vehicle system?"

The study is divided into different phases to answer this research question. First of all, the current situation is analysed and the performance is determined. Next, a literature review is performed to find possibilities on the use of a milkrun or AGV system. After the literature review, the proposed systems are simulated to choose the best suitable option and to provide insight on the implementation of that option. Based on this study, the conclusions described below can be made. The conclusions are described per phase of the study.

Analysis of the Current Situation

Within Bosch Thermotechniek Deventer, BV materials are transported from the warehouse to the production lines by using forklifts. As forklifts have to be removed from the production area, the forklifts need to be efficiently replaced by a milkrun or AGV system. As each percentage of reduction in the service level costs *(confidential)* extra yearly, the new system is required to have a service level of at least 99%. No data was known on the performance of the current BV logistics in terms of meeting required replenishment times and therefore, the service level of the process. Because of this, at first the current situation has been analysed in order to provide insight in the performance and to have a basis for comparing the proposed future situations.

The BV logistics is simulated, together with all other traffic, in Siemens Plant Simulation. Based on the production planning of 2018, the process is analysed on its performance for delivering materials on time. For the current situation, two experiments are performed. At first, the current traffic rules are simulated, and next the future traffic rules. The future traffic rules need to be applied whether forklifts are replaced or not, since this is in line with the safety regulations that should be maintained. Therefore, the performance of the current situation according to the future traffic rules is used for comparing the performance of future situations.

Table 18 shows the performance of the experiments about the current situation with forklifts. When looking at the future traffic rules, the following performance is shown. The average replenishment time over the entire year is 17.6 minutes, with a service level of 99.957%. The yearly costs of the process, concerning labour and equipment costs, is *(confidential)*. Besides the process costs, the yearly loss of production is *(confidential)*, as production workers have to wait for materials to be delivered. Therefore, the total yearly costs are *(confidential)*.

<table>
<tr><th>Simulation study</th><th>Avg. replenish time [min]</th><th>Total number of orders</th><th>Orders within replenish time</th><th>Orders too late per year</th><th>Yearly costs of process</th><th>Investment costs</th><th>Production loss per year</th><th>Service level</th></tr>
<tr><td>Current Situation - Current Traffic Rules</td><td>15.0</td><td colspan="6" rowspan="2">Confidential</td><td>99.990%</td></tr>
<tr><td>Current Situation - Future Traffic Rules</td><td>17.6</td><td>99.957%</td></tr>
</table>

Table 18: Results Simulation Studies of the Current Situation

Analysis of the Future Situation

In the literature review, several options were found on the implementation of a future situation. However, the layout of the production plant has its limitation in terms of required material handling in the warehouse and the available space in the production area. Taking the requirements and limitations in account, an analysis is performed with several settings for both the BV milkrun system and BV AGV system. The settings are simulated to provide insight in the quantitative performance in terms of the service levels and costs. Next, the qualitative performance is analysed, considering the perspective of the employees. Table 19 shows the results of the simulation studies. The best setting for both the milkrun system and AGV system are compared with the current situation and amongst each other. These settings are the cheapest experiments that have a service level above the threshold that is set. One can see that the service level of both future situations is above the threshold of 99% and even above the service level of the current situation. The results stated in the table are further discussed below.

<table>
<tr><th>Simulation study</th><th>Avg. replenish time [min]</th><th>Total number of orders</th><th>Orders within replenish time</th><th>Orders too late per year</th><th>Yearly costs of process</th><th>Investment costs</th><th>Production loss per year</th><th>Service level</th></tr>
<tr><td>Current Situation - Future Traffic Rules</td><td>17.6</td><td colspan="6" rowspan="3">Confidential</td><td>99.957%</td></tr>
<tr><td>Future Situation - Milkruns</td><td>20.0</td><td>99.997%</td></tr>
<tr><td>Future Situation - AGVs</td><td>13.6</td><td>100.000%</td></tr>
</table>

Table 19: Results of the Simulation Studies

The milkrun system requires the most process changes, as the return of packaging material and empty pallets is no longer a separate process. Considering the ergonomics, this is the better situation as production workers do not have to handle the empty pallets anymore. However, when considering changes, the AGV system is the most convenient, as this system does not require major changes in the processes. The only adjustment is that orders are prioritized in the warehouse. This is not required, but considering the logic of transporting critical orders first and the fact that it can easily be done by hand, the conclusion can be made that this is a convenient way of working in practice.

When looking at the table, the yearly process costs of the milkrun system are relatively high and the AGV system has the least yearly process costs. However, the AGV system needs a high investment due to the fact that specific pallet racks are needed on which the AGV can pick and place the pallets with materials.

Over the years, the milkrun system is the most expensive as the money invested will not be earned back. The implementation of the milkrun system will cost *(confidential)* extra per year, when comparing to the current situation. The AGV system has the least yearly costs, which is *(confidential)* less than the current situation. Including the investment, the ROI is slightly under six years. The ergonomic advantage of the milkruns does not compensate the yearly costs difference of *(confidential)* compared to the AGV system. Therefore, according to this simulation study, the AGV system is the best way to efficiently replace the forklifts for the BV logistics. The average replenishment time is 13.6 minutes with a service level of 100%.

Implementation of the AGV System
Two AGVs need to be deployed for transporting the materials and the picker in the warehouse picks materials according to the priority rule and places them on pallet racks. That is, the Kanban cards that are marked as priority have to be transported before the orders that do not have this mark. Next, an AGV picks the material from the pallet rack and transports it to the allocated location in the production line. After delivering the material, the AGV returns to the warehouse for transporting the next material.

In order to let this process work, the current locations of the BV materials in the production lines have to be changed. Every pallet location needs a pallet rack under which the AGV can drive to deliver the material. The current pallet racks and roller tracks need to be removed and replaced.

The study also concludes to change the SV milkrun route in such a way that it is in line with the traffic directions that are determined and therefore also in line with the BV AGVs. The route only has to change slightly. All roads are still travelled and the total distance to travel is slightly reduced.

8.2 Recommendations and Future Research

Besides the main conclusions obtained during this research, recommendations are made on the future process. This also includes doing a quick research.

The investment of the AGV system accounts for pallet racks on which a material is placed by the AGV. The estimation for the price of the pallet racks is obtained from a manufacturer. On the short term, it is recommended to analyse what makes this pallet racks special and if the pallet racks can be made elsewhere. This could reduce the investment and therefore improve the ROI.

The Kanban card of an order that became empty is put in a collection box on specific locations in the production line. Next, the card is waiting to be scanned by the SV milkrun driver. This can take up to 20 minutes, depending on the SV milkrun schedule. As this waiting time is purely waste, it is recommended to let the production workers scan the Kanban cards themselves. In this case, replenishment times are met easier and even if a critical material cannot be directly transported, there is more time to replenish this material within the required timeframe. To scan the Kanban cards by the production worker, equipment is needed to facilitate that. Future research can show what equipment is needed and what the impact on tact times is.

Future research can be performed on including the return of packaging material and empty pallets in the workload of the AGVs. The required capacity has to be recalculated, as the workload for the AGVs becomes higher. Furthermore, an analysis should be performed on the changes required in the process, as the packaging material and empty pallets are placed at other locations in the production lines. The AGV could pick the stack of packaging material or empty pallets after delivering a material and next, the AGV transports it to the repack department and returns to the warehouse.

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Appendix A – Production Planning 2018

The production planning of 2018 is shown in Table 20. This is the production planning that is implemented in the DES model. The production lines can be operational at full speed (D, meaning each day of the week a full day), operational at half speed (HD, meaning half a day for the entire week), or not operational (N, meaning no days in the week).

Week	B3U	DNA	PROA	TLA	TLB
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
21					
22					
23					
24					
25					
26			Confidential		
27					
28					
29					
30					
31					
32					
33					
34					
35					
36					
37					
38					
39					
40					
41					
42					
43					
44					
45					
46					
47					
48					
49					
50					
51					
52					

Table 20: Production Planning 2018

Appendix B – Number of SV Milkruns per Week

Table 21 shows the number of SV milkruns deployed per week. The number of SV milkruns deployed per week is calculated by the workload of the production lines, based on the production planning shown in Appendix A. Six milkruns are deployed if all production lines are operating at full speed. The workload per production line is calculated at full speed. Next, based on the operational speed per week, the number of milkruns required is calculated per week.

	ProductionB3U	ProductionDNA	ProductionPROA	ProductionTLA	ProductionTLB	Total
Orders	Confidential					
Milkrun workload						

Week	The production lines are operational at full speed, half speed, or not operational	No. of milkruns
1	Confidential	5
2		5
3		4
4		4
5		4
6		5
7		5
8		5
9		5
10		5
11		5
12		6
13		6
14		5
15		6
16		4
17		4
18		4
19		5
20		5
21		5
22		5
23		5
24		5
25		5
26		5
27		5
28		5
29		5
30		4
31		3
32		5
33		5
34		5
35		4
36		5
37		6
38		5
39		4
40		6
41		6
42		6
43		6
44		6
45		5
46		5
47		5
48		5
49		4
50		4
51		5
52		0

Table 21: Calculation Number of Milkruns per Week

Appendix C – Simulation Results of the BV Milkrun System

Table 22 shows the results of the BV milkrun experiments that were considered to perform well after one run and the experiments that could not be excluded after one run. Now that four runs have been performed per experiment, the table shows that not all experiments have a service level of at least 99%. The experiments 1 – 4, 14, 16, 23, and 44 have a service level that is not efficient. Furthermore, the yearly costs of the experiments with three transporters are much higher than the experiments with two transporters deployed.

Simulation study						Avg. replenish time	Total number of orders	Orders within replenish time	Orders too late per year	Yearly costs of process	Investment costs	Production loss per year	Service level [%]
ExpNo	Transp	Wagons	FullTour	Prioritise	Schedule	[min]							
1	2	2	FALSE	TRUE	TRUE	27.54							97.131
2	2	2	FALSE	TRUE	FALSE	27.86							96.843
3	2	2	FALSE	FALSE	TRUE	27.70							95.010
4	2	2	FALSE	FALSE	FALSE	26.90							95.295
5	2	3	TRUE	TRUE	TRUE	20.04							99.997
6	2	3	TRUE	TRUE	FALSE	20.34							99.997
7	2	3	TRUE	FALSE	TRUE	20.04							99.965
8	2	3	TRUE	FALSE	FALSE	20.27							99.909
9	2	3	FALSE	TRUE	TRUE	20.02							99.997
10	2	3	FALSE	TRUE	FALSE	17.38							99.997
11	2	3	FALSE	FALSE	TRUE	20.02							99.967
12	2	3	FALSE	FALSE	FALSE	17.42							99.992
13	2	4	TRUE	TRUE	TRUE	21.85							99.997
14	2	4	TRUE	TRUE	FALSE	609.70							42.719
15	2	4	TRUE	FALSE	TRUE	21.85							99.919
16	2	4	TRUE	FALSE	FALSE	608.68							40.851
17	2	4	FALSE	TRUE	TRUE	21.84							99.997
18	2	4	FALSE	TRUE	FALSE	17.58							99.995
19	2	4	FALSE	FALSE	TRUE	21.84							99.922
20	2	4	FALSE	FALSE	FALSE	17.58							99.985
21	3	1	FALSE	TRUE	TRUE	18.09							99.982
22	3	1	FALSE	TRUE	FALSE	17.22							99.997
23	3	1	FALSE	FALSE	TRUE	18.30							98.970
24	3	1	FALSE	FALSE	FALSE	17.33				Confidential			99.646
25	3	2	TRUE	TRUE	TRUE	17.66							99.997
26	3	2	TRUE	TRUE	FALSE	15.51							99.997
27	3	2	TRUE	FALSE	TRUE	17.67							99.990
28	3	2	TRUE	FALSE	FALSE	15.53							99.997
29	3	2	FALSE	TRUE	TRUE	17.65							99.997
30	3	2	FALSE	TRUE	FALSE	14.29							99.997
31	3	2	FALSE	FALSE	TRUE	17.65							99.990
32	3	2	FALSE	FALSE	FALSE	14.29							99.997
33	3	3	TRUE	TRUE	TRUE	19.97							99.997
34	3	3	TRUE	TRUE	FALSE	15.90							99.997
35	3	3	TRUE	FALSE	TRUE	19.98							99.967
36	3	3	TRUE	FALSE	FALSE	15.90							99.997
37	3	3	FALSE	TRUE	TRUE	19.98							99.997
38	3	3	FALSE	TRUE	FALSE	14.45							99.997
39	3	3	FALSE	FALSE	TRUE	19.98							99.967
40	3	3	FALSE	FALSE	FALSE	14.45							99.997
41	3	4	TRUE	TRUE	TRUE	21.82							99.997
42	3	4	TRUE	TRUE	FALSE	20.53							99.343
43	3	4	TRUE	FALSE	TRUE	21.82							99.922
44	3	4	TRUE	FALSE	FALSE	19.88							98.343
45	3	4	FALSE	TRUE	TRUE	21.82							99.997
46	3	4	FALSE	TRUE	FALSE	14.69							99.997
47	3	4	FALSE	FALSE	TRUE	21.82							99.919
48	3	4	FALSE	FALSE	FALSE	14.69							99.997

Table 22: All Detailed Results of the BV Milkrun Experiments – Expected Scenario