Optimization of the inbound process at Wavin NL

Dealing with variability from dock to stock

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CONNECT TO BETTER

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“The most damaging phrase in the language is: ‘we have always done it this way.’”

US Rear Admiral Grace Hopper (1906-1992)

Preface

This thesis is written as final part of the master programme Industrial Engineering and Management, with a specialization in Production and Logistics management at the University of Twente. The subject of the thesis is the optimization of the inbound process at the distribution centre of Wavin, located in Hardenberg.

I thank my supervisors Peter Schuur and Marco Schutten from the University of Twente for their critical feedback during the discussion sessions.

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Summary

Introduction

Wavin, a manufacturer that produces plastic pipes and fittings, wants to optimize the inbound process at the distribution centre in Hardenberg. When suppliers come to the company in Hardenberg to unload their trucks, the products must be stored in the destined location as soon as possible. Also finished products from Wavin's factories in Hardenberg need to be in stock quickly. This is essential to survive in today's competitive market. Delays in the inbound process have consequences on the whole chain. If products are not in stock, orders cannot be picked and trucks cannot be loaded. The transport carrier cannot deliver the products to customers, which leads to a lower service level. This has impact on the turnover of Wavin. This research project provides solutions that help to optimize the inbound process.

Goals and methodology

The goals of this research are to analyse the current performance and to provide improvements that result in an optimization of the inbound process. The main research question is:

How can the inbound process at Wavin be optimized, taking into account staff capacity and available space?

To answer this question and achieve the goals, we first perform a literature review about inbound processes. Through the use of literature we find scientific support about efficient inbound processes, and we find indicators to measure the performance of inbound processes. Besides that, we describe the current situation of the inbound process and we analyse the current performance. After we have identified the problems that result in underperformance of the inbound process, we test several interventions in practice. Moreover, we construct a simulation model to analyse the impact of scheduled deliveries. We use the outcomes of the experiment in practice and the simulation model to give recommendations about improvements that result in an optimization of the inbound process.

Current situation and performance

We divide the inbound process into three main activities: receive, check, and put away. The inbound process begins when trucks arrive at the distribution centre. Trucks are unloaded and products are stored in the receive area. When products are ready to be checked, they are moved to the check area. In the check area products are registered in the ERP-system and checked on quality and quantity. After that, the put away activity starts. The put away activity, and thus also the inbound process, ends when the products are available for order picking.

We focus on the following flows of goods receipt for inside storage, where the numbers in parentheses represent the percentage of the flow:

- Finished goods from the production departments in Hardenberg (12%).
- Products from other factories of Wavin throughout Europe (52%).
- Trade items from external suppliers (23%).
- Returns from customers and from depots (13%).

We identify six different problems that result in underperformance of the inbound process:

Problem 1 - Performance monitoring:
There is only one performance indicator that is directly related to the inbound process. This results in a lack of visibility.

Problem 2 - Staff capacity:
There is insufficient staff capacity to perform the inbound process efficiently. Moreover, the capacity of the goods receipt team is not related to the number of incoming products and there is no flexible workforce during peak hours.

Problem 3 - Available space:
There is insufficient space to store all products efficiently before the products are available for order picking. Pallets are moved frequently within the warehouse, resulting in a lot of traffic with forklifts in a confined area. Besides that, inbound deliveries are frequently stored on staging areas, resulting in interaction with outbound deliveries.

Problem 4 - Quality and checking:
The check activity is the most labour intensive activity of the inbound process. Lots of products must be repacked on other pallets due to the warehouse design. Besides that, operators work in the sequence of the order list and this results in much walking time by searching for products.

Problem 5 - From checked to stored:
93% of the products are first stored on an interim storage place after the check activity. Operators have more priority for picking outbound delivery than pallet retrieval. 40% of the products are confirmed on their destined location between 7:00-10:00 PM and this results in long put away times.

Problem 6 - Planning of incoming deliveries:
Although procurement planners try to create a constant workflow for the goods receipt team, the planning of incoming deliveries is not efficient. The deliveries are not based on historical data, or in accordance with the goods receipt team.

<u>Conclusions and recommendations</u>
There is not much relevant literature about inbound processes. One of the reasons that may explain the low number of relevant papers about inbound processes could be that “goods receipt is a deceptively simple process in many warehouses” (Tompkins & Smith, 1998). Based on the six problems we test different interventions with an experiment in practice, and we build a simulation model to show the impact of scheduled deliveries. During the research project the productivity of the goods receipt team increased with 5.6% in 2016, compared to the same period in 2015 (week 1 to week 24). The outcomes of the experiment in practice and the simulation model, results in five recommendations (see Table I). All recommendations can be implemented and executed in parallel. Some of the recommendations are already performed or need to be continued. After the table we describe the (expected) results of implementing each individual recommendation.

Number	Recommendation	Responsibility	Already performed?
1	Add one extra operator for the receive activity	Unit leader warehouse	Yes
2	Make all operators at the man-up forklifts responsible for the put away activity	Unit leader warehouse in cooperation with the team leaders	In progress
3	Train operators	Unit leader warehouse in cooperation with the team leaders	In progress
4	Use of performance indicators	Logistics manager in cooperation with IT department	No
5	Reschedule the division of incoming deliveries	Logistics manager in cooperation with Demand & Supply manager	No

Table I – Overview of the recommendations

Recommendation 1 - Add one extra operator for the receive activity from 7:30 to 4:00 PM:
The result of this recommendation is that the operators at the check activity do not have to unload trucks anymore and thus handle products faster. An experiment in practice shows that the average number of working days ago that the current batch at the check activity is unloaded, reduced from 2 working days to 1 working day. Besides that, the operators make fewer mistakes when checking products because the operators can focus on one activity.

Recommendation 2 - Make all operators at the man-up forklifts responsible for the put away activity:
The result of this recommendation is that the put away time reduced from 5:30:33 to 3:24:49 working hours, a reduction of 2:05:44 working hours. Also, the average ratio of occupied space in the interim storage zone is reduced from 64% to 35%.

Recommendation 3 - Train operators:
The result of this recommendation is that warehouse operators are more flexible in performing warehouse activities. Besides that, the trained operators can replace operators in case of illness/holidays. Trained operators can also help during peak hours or with overwork on Saturday.

Recommendation 4 - Use of performance indicators:
The result of this recommendation is that the inbound process is continuously monitored and the employees can act upon these indicators when problems arise. It is useful for the logistics manager but also for the warehouse operators that are involved with the inbound process.

Recommendation 5 - Reschedule the division of incoming deliveries:
The result of this recommendation is a more constant and even workflow. The simulation model shows that the average dock to stock time reduces when the incoming deliveries are more equally divided over the week. When the number of incoming products is equally divided over the week and over the day, the result is a reduction of 2:03:23 hours in the dock to stock time compared to the basic model (from 14:25:49 hours to 12:22:26 hours).

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List of abbreviations

Definition	Meaning
AS/RS	Automated Storage/Retrieval System
BPMN	Business Process Model, and Notation
DFD	Data Flow Diagram
DRP	Distribution Resource Planning
EPC	Event-based Process Control
ERP	Enterprise Resource Planning
FIFO	First In First Out
MFC	Material Flow Control
PI	Performance Indicator
RFID	Radio Frequency IDentification
RGA	Return Goods Authorization
SAP	Systems, Applications, and Products
TO	Transport Order
UML	Unified Modelling Language
VAL	Value Added Logistics
VLM	Vertical Lift Module
WMS	Warehouse Management System

1 Introduction

To obtain a master's degree in Industrial Engineering and Management at the University of Twente, students have to perform a graduation project. This master thesis describes a graduation project done at the company Wavin in Hardenberg. The research topic is optimization of the inbound process. This chapter introduces the graduation project. First, Section 1.1 describes relevant background information about the company. In Section 1.2 we give the motivation of the research. Section 1.3 describes the scope of the project and in Section 1.4 we provide the research questions. Section 1.5 presents the research approach. Then, we describe the deliverables of the project in Section 1.6.

1.1 Background information

Wavin is a, from origin Dutch, manufacturer that produces plastic pipes and fittings. The name Wavin is derived from the combination WAter and VINyl. The first products that were made by Wavin are Poly Vinyl Chloride (PVC) pipes used for the transportation of water. Wavin is the leading supplier in the field of plastic pipe systems in Europe. The company is founded in the 1950s and has more than 5,000 employees, located in over 25 European countries with annual revenues of around €1.2 billion. Since 2012 the company is part of the Mexichem Group. As part of the Mexichem Group, Wavin maintains an international network beyond Europe. Wavin has a network of approximately 120 agents, licensees, and distributors with representation all over the world (Wavin, 2015).

Wavin Hardenberg, where the graduation project takes place, has around 350 employees. The company in Hardenberg has three different factories:

- Injection moulding factory, for example to produce couplers.
- Extrusion factory, to produce plastic pipes.
- Special products factory, to produce customer specific products such as manholes.

Besides products from the factories in Hardenberg, Wavin completes its portfolio with products from other plants of Wavin (internal suppliers) and trade items from external suppliers throughout Europe. The products are stored either outside or inside the distribution centre in Hardenberg. The largest products such as pipes and manholes are stored outside. These products are resistant to weather conditions.

Other products, mostly small products packed in boxes, are stored inside the building. The warehouse is divided in three different storage locations: a full pallet (bulk) area, a box area, and a piece picking area. A part of the bulk area is fully automated. The bulk area is used to pick full pallets, or for replenishment of the box area and the piece picking area. The box area is used to pick boxes or for replenishment of the piece picking area. The piece picking area is used to pick small quantities.

The department where the project takes place is the logistics department. The logistics department is responsible for managing and controlling the logistics processes. Warehouse operations are an important factor in controlling the logistics processes. Wavin coordinates all warehouse operations but the transportation of products is outsourced to third-party logistics providers. Wavin uses a Warehouse Management System (WMS) to control the operations. The WMS is integrated with the Enterprise Resource Planning (ERP) tool Systems, Applications, and Products (SAP).

1.2 Motivation of the research

When suppliers come to the company in Hardenberg to unload their trucks, the products must be stored in the destined location as soon as possible. Also finished products from Wavin's factories in Hardenberg need to be in stock quickly. This is essential to survive in today's competitive market. Delays in the inbound process have consequences on the whole chain. If products are not in stock, orders cannot be picked and trucks cannot be loaded. The transport carrier cannot deliver the products to customers, which leads to a lower service level. This has impact on the turnover of Wavin.

Wavin indicates different problems in the current inbound process that need to be optimized. Wavin identifies the inbound process as: the process from unloading of the products to confirmed arrival in the destined storage location. This means that the product is available for order picking.

The logistics manager of Wavin states that "with the available process and equipment the goods receipt team is not capable to meet today's requirements and standards". He specifies several indicators that can be optimized in the inbound process:

Safety

Within the inbound process there is a lot of traffic in a confined area. The incoming products (mostly pallets) are handled with forklift trucks and are often moved before the products are stored in their destined location. At the same time operators are working on checking, sorting and posting of goods. This is a considerable risk in terms of safety and can lead to accidents with severe injury. Wavin's sick leave target rate is a maximum of 5% and that is indirectly related to the risk of accidents.

Customer satisfaction

The majority of Wavin's revenue comes from products of Wavin's own factories throughout Europe. Wavin completes its portfolio with products from a wide range of vendors. These items are not branded and do not carry a Wavin identification. Customers regard this as a shortcoming. Products without Wavin's article number can lead to longer lead times because checking, sorting, and posting of goods are more time consuming. This can result in lower service levels.

Productivity and stability of lead times

The lack of flow and control leads to losses such as searching for goods, double handling, long lead times, and mistakes that again result in dissatisfaction of customers. The target for productivity of 8 "picks" per man-hour cannot be reached by the goods receipt team. One pick means a unique product with a given quantity that gets its own destination in one of the storage types. For example: one product stacked on two pallets, results in two picks. Besides the problem of reaching the productivity target, there is a lot of fluctuation in the lead times from dock to stock.

This graduation project aims to optimize the inbound process. With an analysis of the current situation we find the problems that result in underperformance of the inbound process. Through the use of an experiment in practice and a simulation model, we provide solutions that result in an optimization of the inbound process at the distribution centre of Wavin.

1.3 Scope of the project

The project focuses on the inbound operations: receive, check, and put away. The inbound process ends when the products are available for order picking. The pick and pack operations as well as shipping to the customers, are out of scope. Figure 1.1 gives an overview of the different warehouse operations.

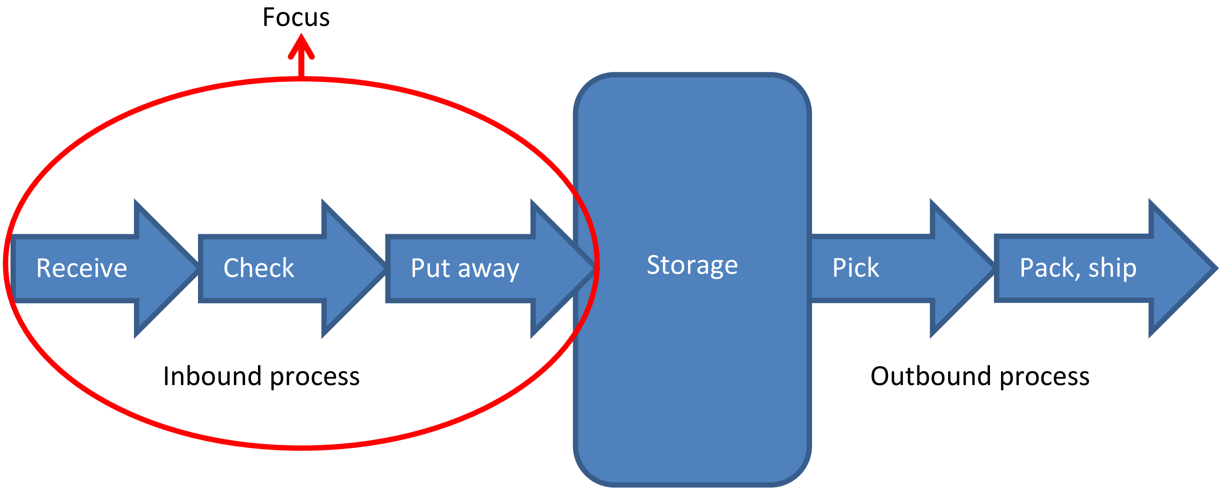


Figure 1.1 – Overview of the different warehouse operations

The scope of the research project is the inbound process of products for inside storage, from product arrival to availability for order picking. According to the logistics manager of Wavin, the scope of the research project contains about 80% of the inbound process at Wavin. We analyse the following flows of goods receipt for inside storage that are handled by the goods receipt team:

- Finished goods from the production departments in Hardenberg.
- Products from factories of Wavin throughout Europe (internal suppliers).
- Trade items from external suppliers.
- Returns from customers and from depots.

The following flows are out of scope:

- Goods receipt of materials such as office supplies and raw materials. Although these materials are handled by the goods receipt team, we do not analyse this flow because these materials are not part of the product portfolio of Wavin.
- Finished goods from the injection moulding factory that need to be packed at the packaging line within the goods receipt building. We do not analyse this flow because these finished goods are not handled by the goods receipt team.
- The inbound process of products for outside storage. These products are resistant to weather conditions. Most of the products that are stored outside are finished goods from the production departments in Hardenberg. These finished goods are put in stock directly after production and thus do not follow the general inbound process.

1.4 Research questions

Based on the indicated problems, the main research question of this project is:

How can the inbound process at Wavin be optimized, taking into account staff capacity and available space?

To answer the main research question we formulate the following sub questions:

1. What has been written in the literature about inbound processes?
   1.1. What has been written about operations of inbound processes?
   1.2. What has been written about performance indicators for inbound processes?
   1.3. What has been written about logistical designs for inbound processes?

2. What is the current situation of the inbound process?
   2.1. How is the logistics process organized, and what are the stakeholders?
   2.2. What are the activities of the goods receipt team?
   2.3. What are the largest suppliers?

3. What is the current performance of the inbound process?
   3.1. Which performance indicators are currently in place and measured?
   3.2. What are the problems of the inbound process?

4. What can be done to improve the performance of the inbound process?
   4.1. Which indicators can be used to measure the performance?
   4.2. What can be done to solve the indicated problems?

Figure 1.2 shows the structure of the thesis. The first two sub questions can be executed in parallel and gives a good starting point for answering the third research question: describing the current performance of the inbound process. After that, we describe the improvements. The final chapter gives the conclusions and recommendations.

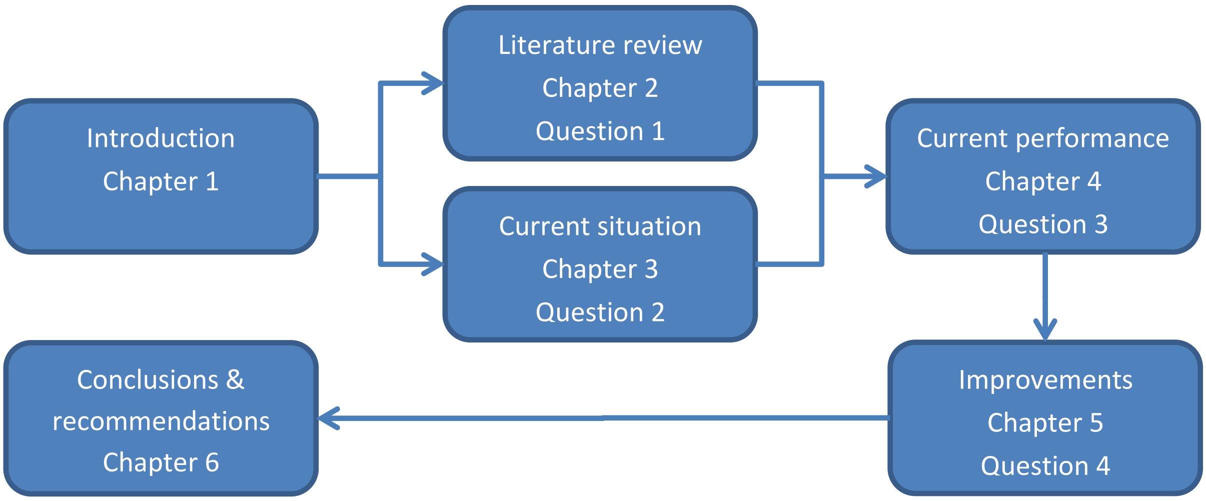


Figure 1.2 - Structure of the thesis

1.5 Research approach

There are different strategies and data collection techniques that we use to answer the research questions. Table 1.1 gives an overview of the methods that are used per research question.

Research Question	Chapter	Monitoring	Interviews & conversations	Literature	Data analysis	Own ideas
1. Literature review	2			X		
2. Current situation	3	X	X		X	
3. Current performance	4	X	X		X	
4. Improvements	5	X	X	X	X	X

Table 1.1 – Research framework

Monitoring

It is important to know how the current inbound process is organized. Cooperation with the team on the floor and observations are useful to get knowledge about the process, and helps to indicate problems. Time-laps or process maps are useful to get an overview of the current situation. Previous research and other relevant documentation the inbound process is analysed to gain an overview of the knowledge that is already in place. Besides that, an experiment in practice or a simulation model can be used to monitor interventions.

Interviews & conversations

Interviews with employees that are involved in the project are necessary to specify which problems the different stakeholders have with the current situation. The stakeholder can be the supervisor or employees from the logistics department but also employees from purchasing, planning, or sales. Moreover, input from people who are working on the floor is essential in succeeding the project. Conversations with employees that influence the inbound process direct or indirect are useful to provide improvement steps.

Literature

The aim of the literature review is to find relevant information about inbound processes. Theoretical knowledge is obtained with the use of literature such as books, papers, websites, and previous essays from other students. In this way, the final recommendations have a theoretical argumentation leading to a higher quality of the research.

Data analysis

An in-depth analysis of the available data from the ERP-system is done in this stage. Think of terms such as forecasting, lead times, waiting times, errors, allocation of products, largest suppliers. Through the use of programs such as Excel, Minitab or SPSS several analyses can be done. We analyse also the performance indicators that are currently in place and measured.

Own ideas

The aim is to get inspired and develop new ideas to optimize the inbound process. Inbound processes at other companies can be helpful to get inspired. Using the learned methods and practices in the master's program, and probably other experiences in the field can also be used in the project.

1.6 Deliverables

This research project provides several deliverables:

- Literature review about inbound processes.
- Analysis of the current inbound process at the distribution centre of Wavin NL.
- Overview with problems that result in underperformance of the inbound process.
- Overview with possible improvements.
- Recommendations on how to implement the improvements.
- Recommendations on performance indicators that can be used.
- Recommendations on the division of incoming deliveries.

This chapter describes the reasons for this research and provides the scope of the project. Furthermore, it presents the research questions. Chapter 2 answers the first research question regarding the available literature about inbound processes.

2 Literature review

Chapter 1 describes the motivation of the research and it presents the research questions. This chapter provides relevant literature about inbound processes. Section 2.1 describes literature about the operations of inbound processes. We present different indicators to measure the performance in Section 2.2. We describe available designs of inbound processes in Section 2.3. Section 2.4 provides the conclusions of this chapter.

2.1 Operations of inbound processes

Warehouses are an essential component in almost every supply chain. Inbound operations within warehouses begin with unloading and checking of inbound trailers. When the products are checked, the products can be stored in the warehouse. The outbound operations begin when the products are retrieved, based on a customer order, and assembled for shipment. The final operation is dispatching the goods onto outbound trailers (Buijs, Vis & Carlo, 2014).

Tompkins and Smith (1998) compare the warehouse operations with military life. 'Hurry up and wait' is an old army expression that also applies to warehouses. Warehouse managers have to deal with peak conditions and this requires a detailed scheduling of the different activities. The manager must ensure a predictable and even workflow and avoid the 'hurry up and wait' scenario. This scenario leads to waste of man-hours and equipment.

Material handling is one of the key factors within warehouses. Goor, Van Amstel, and Van Amstel (1989) define material handling as the internal transport, movement, or the physically shift of materials. Materials could be raw materials, semi-finished products, or finished products. Material handling of raw materials is excluded in this project. Objectives of material handling are:

- Maximizing space utilization
- Minimizing intern travel distances
- Elimination of unnecessary handling
- Realizing an efficient flow of goods
- Keeping flexibility to deal with changes in the material flow
- Minimizing investment costs

New management philosophies such as Just-In-Time and Lean Six Sigma can be useful to achieve shorter response time, better inventory control, and helps to deal with more product variety in warehouse systems. Moreover, the enormous growth of technologies such as radio frequency communications, Warehouse Management Systems (WMS), and bar coding provides possibilities to improve warehouse operations (Gu, Goetschalckx & McGinnis, 2007). It is a challenge for companies to use all this generated data in an efficient way (Khabbazi, Hasan, Sulaiman, Shapi'i & Eskandari, 2013).

Tompkins and Smith (1998) state that "goods receipt is a deceptively simple process in many warehouses". Almost all effort within warehouse operations is focused on order picking and shipping since these activities are the most labour intensive. Another reason could be that companies have "much less information and control on the inbound transportation than on the outbound transportation" (Larbi, Alpan, Baptiste & Penz, 2011).

Gu et al. (2007) categorize the papers about operational warehouse problems within the following topics: receiving and shipping (4), storage (53), and order picking (67), where the numbers in parentheses represent the number of papers as reviewed by Gu et al. (2007). Golovatova and Zhou (2009) conclude that "an enormous gap is still existing between theoretical research and practical operations of incoming goods processes". One of the reasons that research is mainly focused on storage and order picking is because it has the largest impact on the performance of warehouses.

We divide the inbound operations into three different activities: receive, check, and put away. In Sections 2.1.1, 2.1.2, and 2.1.3 we discuss these activities.

2.1.1 Receive

The receive process is the first activity within warehouse operations and involves an orderly receipt of all materials entering the warehouse. The orderly receipt contains several handlings. Products are unloaded at the dock, and if the delivery is complete the operator signs a transportation document. The operator counts the goods and registers it into the WMS.

Van Den Berg (2007) specifies four order types for incoming goods. Goods ordered from different external suppliers are listed on a purchase order. Finished goods from the production plant are specified on a production order. Goods that are received from another distribution centre or another production plant within the same company are listed on a transfer order. The last source of incoming goods is customer returns. Customer returns is an time-consuming variation of goods receipt that has many potential problems. The first thing is to check if the customer is allowed to return the goods due to the warranty terms and warranty period. In general customers have to apply for a Return Goods Authorization (RGA). If the RGA is approved, the customer receives a RGA number that is registered in the ERP-system (Van Den Berg, 2007). Table 2.1 describes the different order types and the relation with this project.

Order type	Source	Source within this project (Wavin)
Purchase order	Supplier	External suppliers
Production order	Production plant	Extrusion Injection moulding Special products
Transfer order	Distribution centre	Internal suppliers
Return Goods Authorization (RGA)	Customer	Returns from customers and depots

Table 2.1 - Order types per source

2.1.2 Check

After the receive activity, the check activity starts. Products must be checked on quantity as well as on quality. "Products such as chemicals, cut flowers, or fresh food may need a quality inspection at every receipt" (Van Den Berg, 2007). After the check activity, a unique identification label is attached. Using for instance a barcode label or a RFID (Radio Frequency IDentification) tag, the movements of the pallets can be tracked into the WMS. The implementation of WMS increases the importance of the inbound process. Implementation of a WMS might lead to extra time spent on the process, but the lost time can be gained back later in the process. Via electronic interfaces, the WMS may receive information about the incoming products.

Therefore the WMS knows beforehand which orders and deliveries are expected. If the WMS contains this information, the operator can compare the received quantities to the purchase order or receipt advice. Goods arrival without any formal agreement is called a surprise receipt (Frazelle & Frazelle, 2002; Van Den Berg, 2007).

Efficient storage and order picking can only be done when the receive activity and the check activity are managed quite well. A poor inbound process leads to problems in further stages as it is the setup for all other warehouse activities. One of the problems is acceptance of damage. Poor control of damage on incoming products can lead to high expenses. Allowing damaged or incorrect inbound deliveries can lead to damaged or incorrect outbound deliveries. This results in customer dissatisfaction. Quality inspections can be done to avoid these pitfalls. Operators must register an error when products are damaged, missing or do not meet other requirements. Deliveries are usually warranted for a certain period. During this period, e.g. one week, errors in the goods receipt can be claimed from the sender. Clear agreements with suppliers are very important to deal with certain situations. Another difficulty in inbound processes is the variety in pallet sizes and pallet types such as pallets with collars or mesh box pallets. Repacking or restacking of products, or restacking of products onto other pallets is also time-consuming. (Frazelle & Frazelle, 2002; Tompkins & Smith, 1998; Van Den Berg, 2007; Van Vliet, 1998).

Another important task is checking of returns. This must be done structurally. The first checking issue is whether the product is still saleable. Operators must consider if the product can be put in stock again. Products can be incomplete or might be damaged. Mostly, customers send products back to the supplier in reused boxes or with own packaging material. If the product is saleable, the second issue is to determine what additional steps are needed to make them saleable again. Reconditioning can be an example of such an additional step. In the worst case the products must be thrown away. Returns require more handling than other receipts, and the inbound process must include both time and space to handle these returns (Tompkins & Smith, 1998).

2.1.3 Put away

During the put away activity, products are moved to their destined storage location. This can be a bulk area or a piece picking area. A bulk area, also called reserve area, typically contains full pallets. It is customary to pick full pallets or for replenishment of the piece picking area. A piece picking area, also called forward area, contains individual cases and pieces. As the name suggests, the piece picking area is used to pick small quantities.

Products can be moved into their destined location in a single-step move or a multi-step move. If a forklift driver moves the products directly from the check area to the destined storage location it is called a single-step move. When the products are first moved from the check area to an intermediate storage location, such as a pick/drop point at the front-end of an aisle, it is called a multi-step move. All these movements are guided by the WMS. Sometimes products are directly moved from the inbound process to an outbound truck, so called cross-docking. Many papers are written about cross-docking operations but cross-docking is currently not used at the distribution centre of Wavin. When the put away activity is finalized, products become available for order picking (Rouwenhorst et al., 2000; Van Den Berg, 2007).

2.2 Measures of inbound processes

The pressure on warehouse operations is to continuously increase productivity and accuracy while reducing costs and inventories, and improve the customer service level (Richards, 2014). Maximizing customer value is the objective of continuous improvement. It is important to first determine what customers define as value. If this is known, maximizing customer value can be done by reducing waste (Malta & Cunha, 2011). Different indicators can be used to identify waste and to measure the performance of inbound processes:

<u>Time</u>

The lead time of the inbound process can be used as a time measure. This is the average lead time from product arrival to availability for picking, also called the dock to stock time (Staudt, Di Mascolo, Alpan & Rodriguez, 2014). The receive, check, and put away activity can also be measured individually to encounter specific problems. The dock to stock time can be calculated as follows. If the sum of the time between the arrival up to product storage is 1000 hours and the number of pallets unloaded is 200, the average dock to stock time is:

$$\frac{1{,}000\ hours}{200\ pallets} = 5\ hours\ per\ pallet$$

<u>Productivity</u>

Another useful indicator can be productivity, measured in the number of handled 'picks' per man-hour. One pick can be a full pallet or an individual piece that gets its own destination in one of the storage types. The measure of picks per man-hour can also be split up into receive, check, and put away to identify problems in the process. If, in a certain period there are 10,000 picks and 2,000 man-hours involved in the inbound process the average picks per man-hour is:

$$\frac{10{,}000\ picks}{2{,}000\ man\_hours} = 5\ picks\ per\ man\_hour$$

<u>Costs</u>

A measure to identify the costs of the inbound process is to multiply the hourly wage by the total man-hours and divide this with the total picks or order lines. Van Vliet (1998) states that the number of order lines is useful because it is more detailed than the number of incoming orders. So if the hourly wage is €35.00 and using the same numbers as the productivity example the result is:

$$\frac{€35.00/man\_hour}{5\ picks/man\_hour} = €7.00\ per\ pick$$

<u>Quality</u>

One of the indicators to measure quality is the percentage of order lines that is handled correctly. Correct could be in the right amount or in the right time if there are appointments about the maximum handling time of checking products.

$$\frac{Number\ of\ incoming\ order\ lines\ handled\ correctly}{Total\ number\ of\ incoming\ order\ lines} * 100\%$$

Another measure is the percentage of delivered goods at the agreed delivery date. With this measure every supplier can be measured on their service rate. Through the use of unique identification labels, scanning pallets is sufficient instead of identifying, counting, and registering the received goods. The frequency of quality checks can be based on the service rate of the supplier. Thus, a supplier with a low service rate is always checked, and a supplier with a high service rate can be checked at random (van den Berg, 2007).

Utilization

Another indicator is a space density factor. This is the percentage of utilized space. This measure can be used for the receive area, check area, or interim storage area to check if additional space is needed (Bozarth & Vilarinho, 2010).

$$\frac{Utilized\ space\ in\ square\ meters}{Allocated\ space\ in\ square\ meters} * 100\%$$

Flexibility

The workload of the inbound process usually fluctuates a lot. The way in which these fluctuations are handled is a measure of flexibility. The difference between the average man-hours and the maximum man-hours spent per week in a certain period could be an indicator. Another example could be the percentage of man-hours performed by temporary staff relative to the total man-hours spent in the inbound process (Van Vliet, 1998).

$$\frac{Man\_hours\ performed\ by\ temporary\ staff}{Total\ man\_hours\ spent\ in\ the\ inbound\ process} * 100\%$$

2.3 Designs of inbound processes

The increasing trend of more product variety and short response times leads to pressure on logistics operations. Therefore smooth and efficient logistics operations are needed to deal with this trend. Since logistics costs are an important part of overall production costs, efficient logistics operations plays a role in the competitiveness of a company (Rouwenhorst et al., 2000). The design of inbound processes is part of the logistics operations. The layout of the goods receipt area must be designed efficient to handle goods fast (Goor et al., 1989).

Larbi et al. (2011) provide three transhipment scheduling policies for cross-docking operations under different levels of information on incoming transport. In the first policy, the assumption is that there is complete information on the order of arrivals and the contents of all inbound trucks. The second policy provides a scheduling method with the assumption of partial information on the sequence of upcoming trucks. The last policy assumes that there is no information of upcoming trucks. An example of partial information could be knowledge about the average volume of deliveries based on historical data. This scenario is most common in distribution warehouses, although the scenario of complete information is becoming increasingly common through the use of advanced information technologies such as RFID (Gu et al., 2007). Stacey, Natarajarathinam, and Sox (2007) describe several models to combine deliveries from suppliers that deliver low to medium volumes to the same customer.

Khabbazi, Hasan, Sulaiman, and Shapi'i (2014) check the suitability of the material workflow modelling tools Data Flow Diagram (DFD), Event-based Process Control (EPC), Business Process Model and Notation (BPMN), and Unified Modelling Language (UML) activity diagrams. A workflow of receiving purchased goods in inbound logistics systems is examined. With each modelling tool a process-based workflow model is developed and a UML activity diagram is demonstrated as the best one.

Another thing that is related to logistical designs of inbound processes is the design of the receive area. The design is based on the sequence of handling incoming deliveries in the check activity. Gorter (2015) describes different options to make the delivery day of products that are already unloaded visible. One of them is to put a sticker on the delivery that changes colour after a certain period. This indicates which products should be processed first, based on the preference of the company. When the company decides to handle products on a First In First Out (FIFO) rule an option could be to use FIFO-lanes. This means that deliveries are checked in the sequence of their delivery day. A design of the receive area could be to use two different areas to place products. One area for products that arrived yesterday or earlier, and one area for products that arrive on the present day. The yesterday area must always be empty before processing products from the today area. Drawback of this approach is that at the end of the working day, products that are not handled yet must be moved to the yesterday area. Another option is scanning the tracking number on the waybill of the delivery. This can be used in the WMS to compare the time between a product arrives and the time a product is processed. Companies can use this data to show which products should be processed first.

The characteristics of incoming products such as amount, volume, quality, and packaging material usually change over time. Therefore Golovatova and Zhou (2009) state that the inbound process should be reorganized and restructured timely in order to efficient control the inbound process. Tools such as systematic layout planning or systematic warehouse planning can be used to redesign the layout.

2.4 Conclusion

This section provides short answers on the formulated research questions.

1. <u>What has been written in the literature about inbound processes?</u>

There is not much relevant literature about inbound processes. Papers that discuss inbound processes are very general and do not provide in-depth information. Golovatova and Zhou (2009) state that there is an enormous gap between theoretical research and practical operations of incoming goods processes. This statement is emphasized by the low number of available papers. Gu et al. (2007) categorize the papers about operational warehouse problems within the following topics: receiving and shipping (4), storage (53), and order picking (67), where the numbers in parentheses represent the number of papers as reviewed by Gu et al. (2007). Research is mainly focused on storage and order picking because it has the largest impact on the performance of warehouses. One of the reasons that may explain the low number of available papers about inbound processes could be that "goods receipt is a deceptively simple process in many warehouses" (Tompkins & Smith, 1998).

1.1. What has been written about operations of inbound processes?

The operations of inbound processes can be divided into three main activities: receive, check, and put away. Larbi et al. (2011) state that companies have “much less information and control on the inbound transportation than on the outbound transportation”. Therefore it is difficult to schedule the staff capacity for inbound operations.

Another thing found in literature is to avoid the ‘hurry up and wait’ scenario: in general warehouses have to deal with high fluctuations in their daily activities (Tompkins & Smith, 1998). This fluctuation must be avoided as much as possible to create a predictable and even workflow, and be able to schedule the capacity of the staff efficiently.

1.2. What has been written about performance indicators for inbound processes?

There are different indicators to measure the performance of the inbound process. The indicators can be divided in the dimensions time, productivity, costs, quality, utilization, and flexibility.

1.3. What has been written about logistical designs for inbound processes?

There is almost no literature available about useful (re)designs of inbound processes. Larbi et al. (2011) provide three transhipment scheduling policies for cross-docking operations under different levels of information of incoming transport: full information, partial information, or no information on the order of arrivals and the contents of inbound trucks. Golovatova and Zhou (2009) state that the inbound process should be reorganized and restructured timely to be able to deal with changes on inbound deliveries.

This chapter gives insight into the available literature about inbound processes. Chapter 3 describes the current situation of the inbound process at the distribution centre of Wavin NL.

3 Current situation

Chapter 2 describes relevant literature about inbound processes. This chapter describes the current situation of the inbound process at the distribution centre of Wavin. Section 3.1 discusses the logistics processes at Wavin with the different stakeholders that are involved with the inbound process. In Section 3.2 we describe the different activities of the inbound process. Section 3.3 analyses the largest suppliers and Section 3.4 provides the conclusions of this chapter.

3.1 Logistics process and stakeholders

Logistics is an important part within the supply chain of Wavin. Goldsby and Martichenko (2005) state that "there seem to be as many definitions of 'logistics' as there are logisticians". The aim of the logistics department is to serve customers efficiently. Customers want the ordered products in the right time, in the correct quantity, at the right place against the lowest costs (Richards, 2014). The logistics department uses logistics processes to achieve this. The logistics processes are supported by a Warehouse Management System (WMS) that is integrated with the ERP-system SAP. Every movement of a product within the warehouse is monitored in SAP. Scanners and other digital equipment are used to collect this data. The data is used to control the logistics processes and to measure the different performance indicators.

We discuss the logistics process in further detail per stakeholder in Sections 3.1.1, 3.1.2, and 3.1.3. Different stakeholders are involved in the inbound process: Demand & Supply, Sales & Marketing and Logistics. The names of the stakeholders are based on organizational charts of Wavin.

3.1.1 Demand & Supply department

The Demand & Supply department is one of the stakeholders of this project and has different responsibilities (see Figure 3.1). The department is headed by the Demand & Supply manager. Procurement planners use Distribution Resource Planning (DRP) to purchase products. DRP is a method for the planning of orders within a supply chain. Maintaining master data and making detailed schedules for the factories are also tasks of the Demand & Supply department.

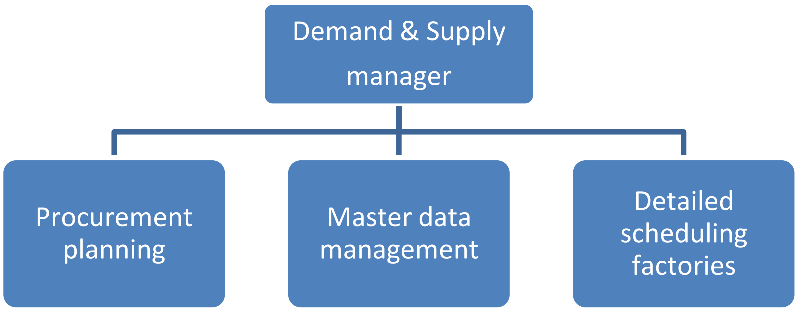


Figure 3.1 – Overview of the Demand & Supply department

The team leader of the procurement planners at the Wavin plant in Hardenberg, states that other factories of Wavin schedule deliveries to each other based on a push system. For example: the Wavin company in Poland generates a stock movement to the Netherlands based on different control parameters such as safety stocks. Some of the Wavin factories throughout Europe deliver products to Hardenberg daily. Wavin completes its portfolio with trade items from about 250 external suppliers and a few of them have fixed delivery days. One of the goals of the fixed delivery days is to create a constant workflow for the goods receipt team.

Supplier selection and price negotiations are done by strategic buyers in cooperation with product managers. Strategic buyers and product managers are not under supervision of the Demand & Supply manager.

The relation of the Demand & Supply department with this project is that the department influence the incoming deliveries. If, for example, the minimum stock level of Stock Keeping Units (SKUs) is incremented, deliveries are scheduled to fulfill this change. Therefore it is important to discuss possible changes of deliveries with the goods receipt team, in order to schedule the capacity of the goods receipt team and trying to create a constant workflow.

3.1.2 Sales & Marketing department

This department is supervised by the director of Sales & Marketing. Wavin sells their products in different segments that are divided in: Civil & Infra and Building & Installation. The department coordinates the sales in the different depots and is responsible for marketing within the Netherlands. Figure 3.2 shows the different units of the Sales & Marketing department.

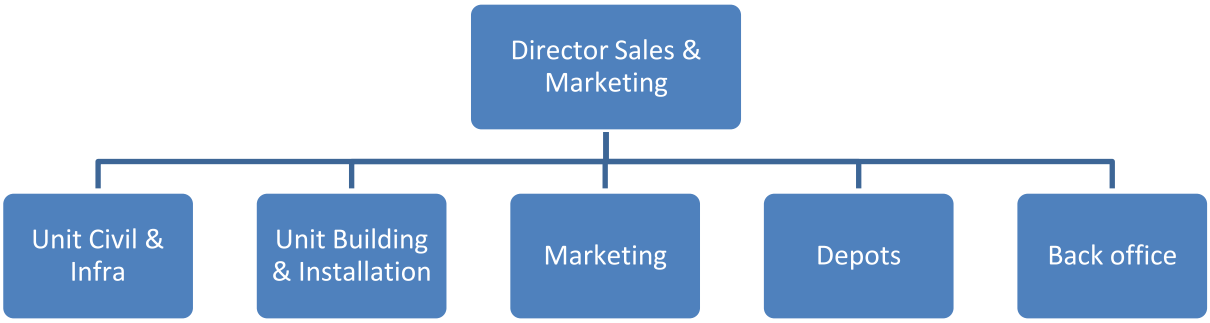


Figure 3.2 – Overview of the Sales & Marketing department

The relation with the project is clear: products must be in stock to sell them. The sales department makes agreements with customers about delivery dates. The sales department assumes that the incoming products are available for picking within 48 hours after arrival at the distribution centre. The back office manager noticed that it is sometimes difficult that products cannot be sent to customers before the products are confirmed on the destined storage location in the warehouse. Employees can make a sales order for products that are already received, but if a material is not confirmed on the destined location yet, the products cannot be sent to the customer. Cross-docking is currently not used at the distribution centre of Wavin.

3.1.3 Logistics department

The logistics department is the main stakeholder of the project and is supervised by the logistics manager. Figure 3.3 shows the organizational chart of the logistics department. After the figure we describe the following four units:

- Inside warehouse
- Outside warehouse
- Process optimization and system support
- Distribution planning

The goods receipt team that we describe in this research project is supervised by two team leaders of the inside warehouse.

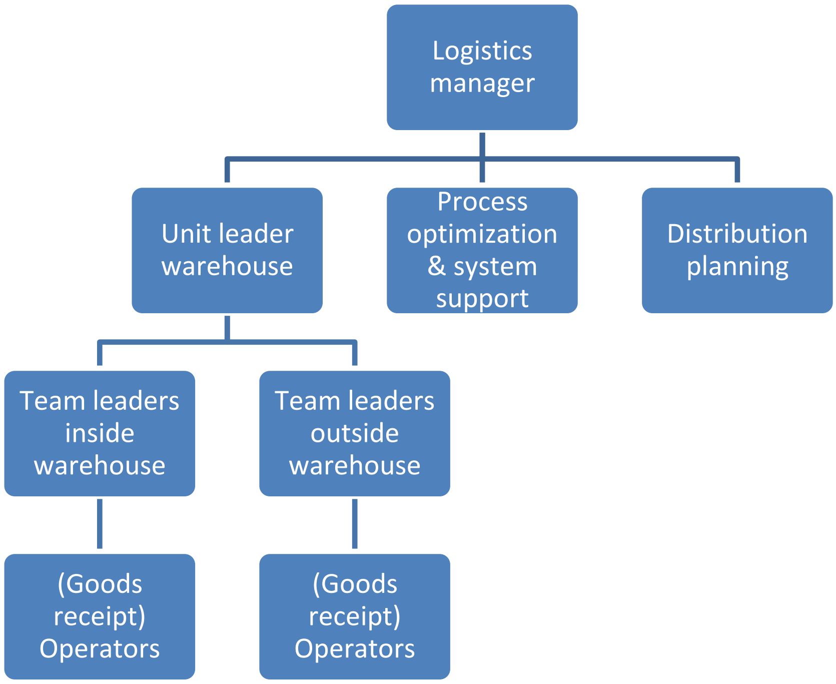


Figure 3.3 - Overview of the logistics department

Inside warehouse

The operators of the inside warehouse are responsible for the distribution of all the products that are stored inside the warehouse. The general steps that a product follows can be divided into: goods receipt, storing, staging, and loading (see Figure 3.4). Section 3.2 discusses the specific activities of the goods receipt step.

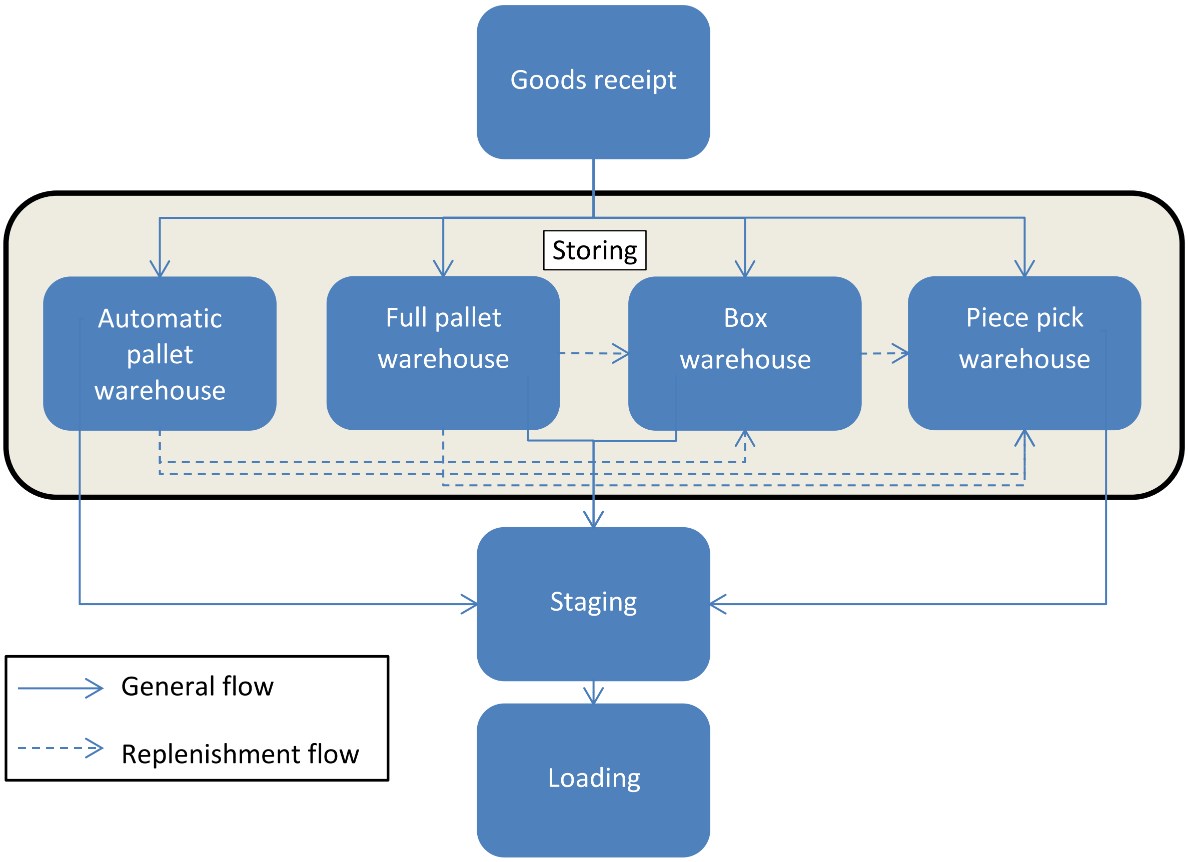


Figure 3.4 - Process flow inside warehouse

Outside warehouse

The process flow for the outside warehouse is almost the same as for the inside warehouse. The main difference is that the products have more volume. The largest surface of the company is used to store these products. This can be manholes, fittings, roles, pipes wound on steel drums, or pipes with a length up to 24 meter. The products are handled by cranes or forklifts. The relation with the project is that some of the products for the outside warehouse are received by the staff of the inside warehouse, mostly products stacked on pallets.

Process optimization and system support

As the name suggests this unit supports the logistics department. The employees of this unit keep track of efficient warehouse processes. They try to develop solutions when operators encounter problems in the logistics processes. Logistics specialists have in-depth knowledge of the process and work on continuous improvement, such as new warehouse layouts, rack designs, and pick strategies. Data analysis, master data management, and keeping track of the different performance indicators are also part of their daily activities.

Distribution planning

The distribution planning unit schedules the transport of goods and prepares work for the warehouse staff in order to efficiently execute the staging and loading step (see Figure 3.4). There are three different delivery types, namely the two days flow, one day flow, and the distribution flow. Orders for the two days flow must be posted before 2:00 PM on working day 1 and are delivered on working day 3 between 7:00 AM and 5:00 PM. Orders for the one day flow must be posted before 11:00 AM and are delivered the next working day. Orders for the distribution flow must be placed before 5:00 PM and will also be delivered the next working day. The distribution flow consists of products with low volumes. Figure 3.5 shows the timeline of the different delivery types. The transportation of the different types is outsourced to third-party logistics providers and the distribution planners are responsible for the contact with these providers. Distribution planners also coordinate the paperwork for the outbound deliveries.

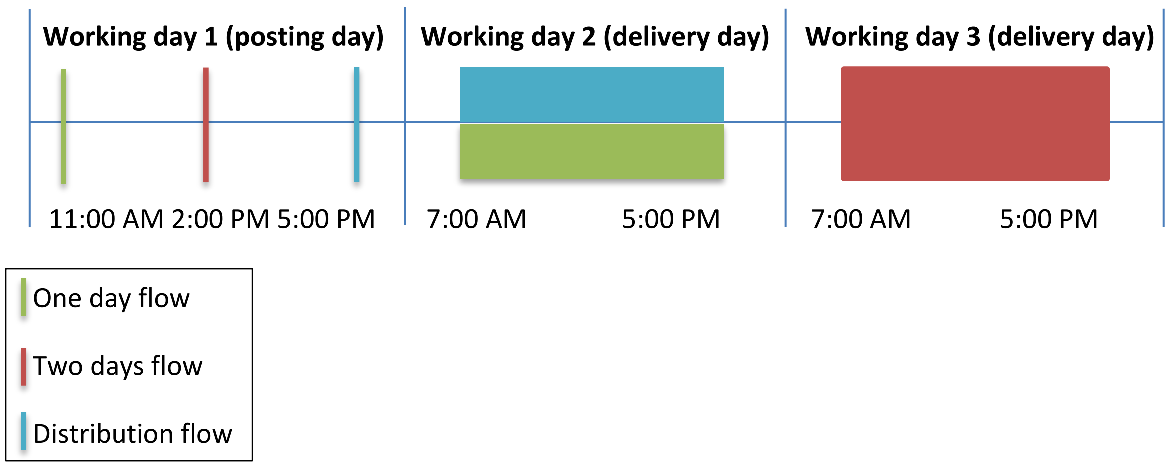


Figure 3.5 - Timeline different outbound deliveries

3.2 Activities of the goods receipt team

The activities of the goods receipt team can be divided into three activities: receive, check, and put away. Figure 3.6 gives an overview of the activities and Appendix A shows the floor map of the inside warehouse. We describe the different activities in Sections 3.2.1, 3.2.2, and 3.2.3. The descriptions are based on observations and describe the general way of working without exceptions. Returns are excluded in order to give a clear description of the activities. Section 3.3.3 describes the handling of returns.

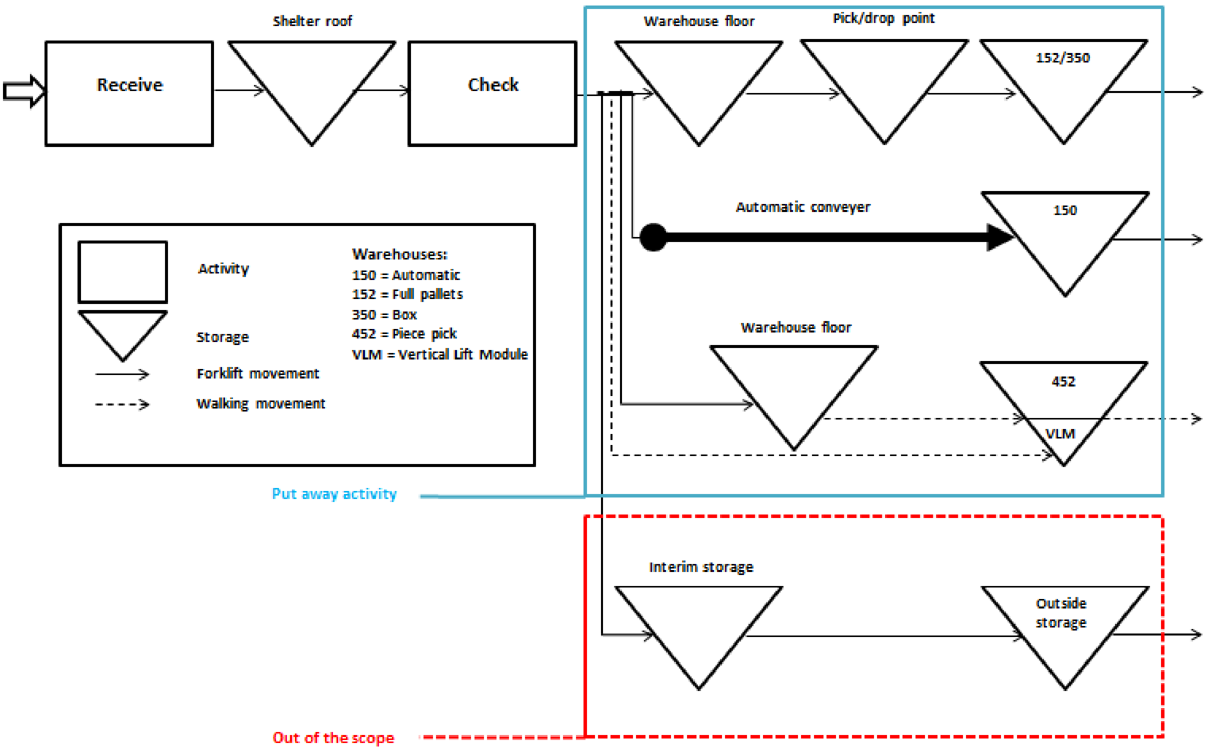


Figure 3.6 - Overview of the different activities

3.2.1 Receive

When trucks come to the company to unload their goods the inbound process begins. The truck driver must have a packing list that must be presented to one of the goods receipt operators. The operator writes the day of delivery on the packing list and stores the packing lists per day. The operator can begin with unloading the truck when the paperwork is right. Unloading of the truck is done by using a forklift. Products are stored on an interim storage place under a shelter roof. The products are most of the time sorted in sequence of unloading. The last unloaded pallet of the delivery is the first pallet that is handled in the check activity. The date of delivery is noted on this last unloaded pallet to get some visibility on the arrival dates.

3.2.2 Check

Checking products is the most labour intensive activity of the inbound process. Products from the interim storage place under the shelter roof are moved to the check area with the use of a forklift. In general products are checked based on the First In First Out (FIFO) rule. This means that deliveries are checked in the sequence of their delivery day. The delivery with the earliest arrival date is checked first, only on daily basis and not on exact times.

Sometimes there are priority cases due to out of stocks or delayed delivery of products. Also products from own production are checked directly. Based on the order number of the delivery the operator prints a list with information about the ordered products. This list (called GETI-list in SAP) contains information about the delivery such as article numbers, number of products, destined storage types, and storage units. Together with the packing list the GETI-list is used to check the order. Most of the products are packed in boxes and stacked on pallets. There is a lot of variety in pallet sizes and pallet types such as pallets with collars or mesh box pallets. If a pallet is sealed, the plastic is removed for several reasons.

One of the reasons is that products must be repacked on special pallets due to the design of the pallet racking system. This four way entry pallet has a dimension of 800x1,200 millimetres. It is non reversible and open boarded. The difference with a EURO-pallet is that the so called 'Wavin Hardenberg' pallet has only bottom deck boards at the short sides of the pallet (see Figure 3.7). EURO-pallets have bottom deck boards at the long sides. Man-up forklifts within the aisles of the warehouse cannot handle these EURO-pallets due to the warehouse design. Pallets are stored in the length and the man-up forklifts can only pick pallets at the pallet opening, the side without bottom deck boards. Unsealing of pallets is also done to check the quality and the number of products. Another reason is that unsealing in this part of the process is the most efficient. It is easier to unseal products on the floor than to unseal it at high rack storage places. Sometimes a pallet collar or tape is needed for stability and safety.

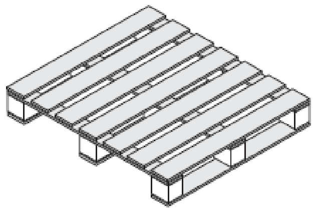


Figure 3.7 - Four way entry pallet with bottom deck boards at the short sides of the pallet

During the check activity the operator also enters data in the ERP-system. The operator enters the date of delivery in the ERP-system that is noted on the packing list. First, the operators perform a "MIGO" booking (goods receipt in the ERP-system) in which the products get a new destination in the data. This is an interim storage location. Based on the information on the GETI-list the operator decides in which storage type the products must be located. Every handling in the ERP-system is called a Transport Order (TO). Some pallets from other factories of Wavin (mostly from Buk Poland) already have a Wavin label that can be scanned. This saves time because most of the data do not have to be entered manually in the ERP-system. If all the data is right, new labels can be printed. These labels are used to transport the products to their destined location. Labels are attached on both short sides of the pallet. A truck lift driver knows to which interim storage place these pallets must be transported. This is the beginning of the put away activity. When the delivery is completely checked, the packing list and the GETI-list are archived and sorted by supplier.

3.2.3 Put away

If the products have a label and the products are checked, the forklift driver moves the products to one of the different (interim) storage locations. The put away activity depends on the storage location of the products and therefore this section describes the put away activity per storage type.

Automatic pallet warehouse (storage type number 150)
The automatic pallet warehouse has 4,231 storage locations and consists of three aisles. A pallet that must be stored in the automatic pallet warehouse is moved from the check area to an automatic conveyer by a fork lift driver. At this point the put away activity is finalized for the operators. The automatic conveyor transports the pallet to the Automated Storage/Retrieval System (AS/RS). The AS/RS picks the pallet and moves it to the destined storage location. Confirmation on location is done automatically. The whole system is connected with the ERP-system by a Material Flow Control (MFC) system.

Full pallet warehouse (storage number 152) and box warehouse (storage number 350)
The full pallet warehouse has four aisles and 3,167 storage locations. The box warehouse has ten aisles and 6,147 storage locations. Both storage locations contains of pallet racks. Pallets that must be stored in one of these storage types are moved to an interim storage location. An operator moves the pallet from the check area to this interim storage space with a forklift. The forklift has long forks to move a maximum of 3 pallets in one time. Another warehouse operator brings the pallets to a pick/drop location at the front-end of the right aisle. This movement is more or less done at random because these operators also have other tasks regarding to outbound deliveries.

A driver of a man-up forklift picks up the pallet from the pick/drop location and scans the label. The digital equipment shows the destined location of the pallet and the driver moves to this location within the aisle. The driver puts the pallet in place and confirms with a scanner that the pallet is stored on location. The step from the pick/drop point to the destined storage location also involves some randomness. Operators at the man-up forklifts are also responsible for picking products for outbound deliveries. Outbound picking can have more priority than pallet retrieval, resulting in longer lead times of the inbound process. The put away activity is finalized when the products are available for order picking.

Figure 3.8 shows a man-up forklift. The operator's cab of the man-up forklift is elevated with the forks to improve visibility. The forklifts are able to travel horizontally and vertically simultaneously to a storage location. With the use of these man-up forklifts, aisles can be very narrow because the man-up forklifts do not have to turn in the aisle. Recall that the pallets are stored in the length instead of the width. Narrow aisle racking makes excellent use of floor space and maximizes the height at which products can be stacked.

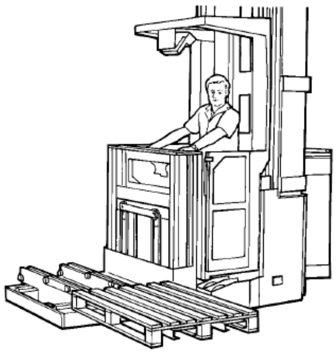


Figure 3.8 - Side loaded man-up forklift (Racking & Warehouse guide, 2016)

Piece pick warehouse (storage number 452)

The piece pick warehouse contains about 4,500 storage locations. Products that must be stored in the piece pick warehouse are moved to an interim storage space. Most of the time, different items are collected on one pallet and an operator moves this pallet from the check area to this interim storage space with a forklift. Products that must be stored in the Vertical Lift Module (VLM) are directly stored by the operator that executes the check activity. An operator of the piece pick warehouse picks up the pallet with a pallet jack and moves the pallet to the piece picking area. The operator scans the barcode of the product and the destination location appears on the screen of the scanner. The operator puts the products in the shelf rack and scans the barcode of the location to confirm that the products are in place. With this confirmation the put away activity is ended.

3.3 Largest suppliers

This section analyses the number of incoming products for a period of three months. The obtained data is used to find the largest suppliers. The analysed period contains 65 working days, 13 full weeks (week 36-48) from Monday 31 August until Sunday 29 November 2015. The period can be seen as a reliable set of data and is confirmed by logistics specialists. The demand in this period is stable without fluctuations due to summer holiday and other non-working days such as Christmas.

The following flows are analysed:

- Finished goods from the production departments in Hardenberg except the packaging line of the injection moulding department.
- Products from other factories of Wavin throughout Europe (internal suppliers).
- Trade items from external suppliers.
- Returns from customers and from depots.

The analysis is done for products that go to one of the four inside storage locations:

- Automatic pallet warehouse (storage number 150)
- Full pallet warehouse (storage number 152)
- Box warehouse (storage number 350)
- Piece pick warehouse (storage number 452)

The goods receipt team has some other tasks that are not included in this analysis. The goods receipt team checks a part of the orders that must be stored outside, mostly products stacked on pallets. The goods receipt team also handles other incoming goods such as raw materials and office supplies. Sometimes there are trucks that must be sent to other departments. The packaging line is also excluded.

General results

In total there are 14,663 records. One record in the data means a unique product with a given quantity that gets its own destination in one of the storage types. One order can have multiple records. More than half of the records are products from internal suppliers of Wavin (see Figure 3.9). Almost a quarter of the records are trade items from external suppliers. The remaining records are from returns (13%) and own production (12%). Recall that most of the finished goods from own production are stored outside and that the packaging line is excluded. This results in a low percentage of goods from own production.

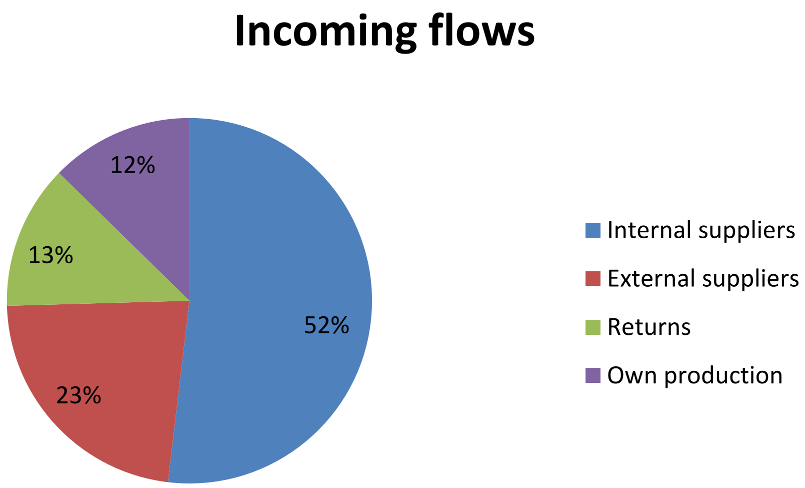


Figure 3.9 - Percentages of incoming deliveries

Figure 3.10 shows the percentages of the different storage types. Only 7% of the products that are handled by the goods receipt team are stored in the automatic pallet warehouse. This percentage is low because all the products from the packaging line are stored in this warehouse type. Another reason is the stability of the delivered products. Only pallets stacked with stable products can be stored in the automatic warehouse due to errors in the automatic handling. Half of all records are stored in the box warehouse and 23% of the records in the full pallet warehouse. Thus, 73% of the records (full pallet and box warehouse) are stored on the same interim storage location.

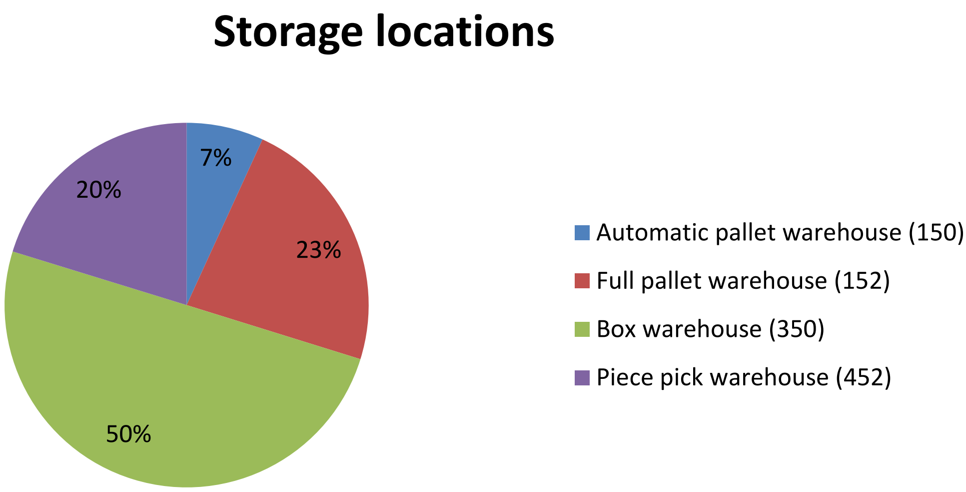


Figure 3.10 – Percentages of storage locations

Sections 3.3.1 to 3.3.4 describe the different incoming flows.

3.3.1 Internal suppliers

52% of the records from the analysis comes from other factories of Wavin throughout Europe. This is a huge number of stock movements under the Wavin flag. The largest internal supplier is the factory in Poland (46% of the records from internal suppliers). Thus, almost a quarter (0.52x0.46x100% = 23.92%) of the records in this analysis comes from one supplier.

Figure 3.11 shows the five largest internal suppliers that deliver the most products to the distribution centre.

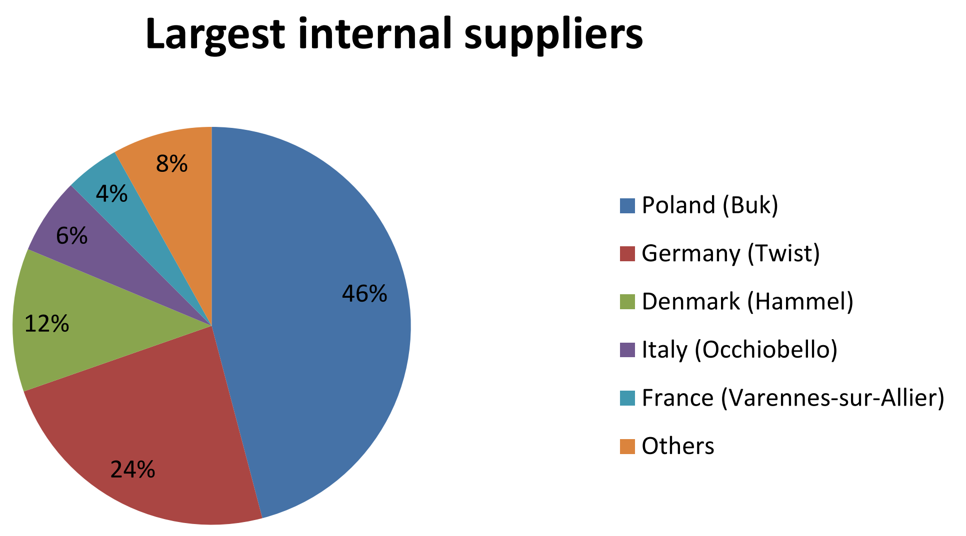


Figure 3.11 - Percentage of incoming records from internal suppliers of Wavin

3.3.2 External suppliers

23% of the total incoming records comes from external suppliers. In the analysed period, 78 external suppliers have delivered products at least once. Five external suppliers are responsible for 49% of all records from external suppliers (see Figure 3.12). The records from Larcom are outsourced production. It is a Value Added Logistics (VAL) service of own production.

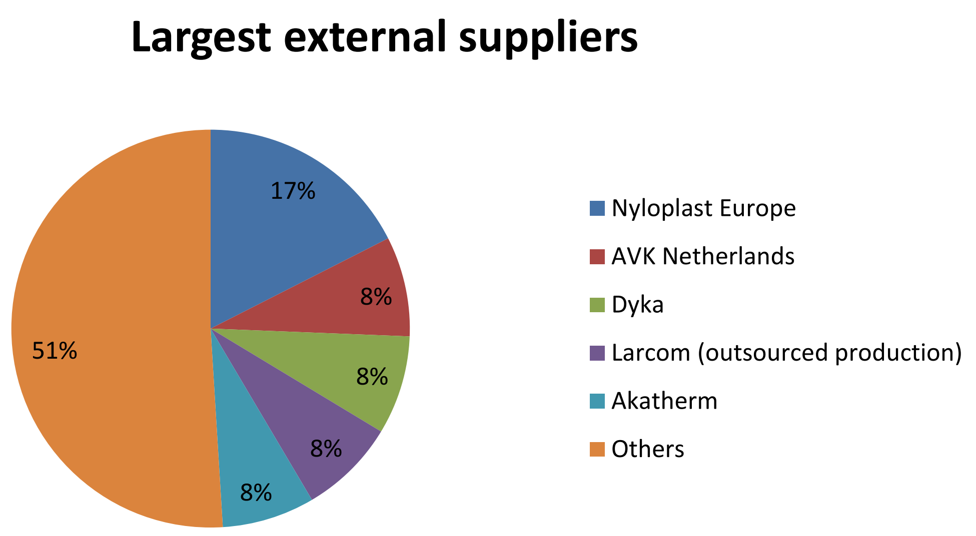


Figure 3.12 - Percentage of incoming records from external suppliers

3.3.3 Returns

Returns can be seen as a different flow of incoming products (13% of all incoming records). Most of the returns are treated by one operator (8 man-hours per day). Checking returns is a labour intensive activity since all returns must be checked on quality. 58% of all returns are actually stock movements from the different depots of Wavin in the Netherlands. Depots sent for example slow movers back.

There is some interaction between the goods receipt team and the person that handles the returns. They help each other when it is needed and forklift handlings are intertwined. This operator also handles the returns for a part of the outside warehouse. An important thing to notice is that 61% of the returns get a destination in the piece pick warehouse (see Figure 3.13). The reason is that a return mostly consists of small quantities.

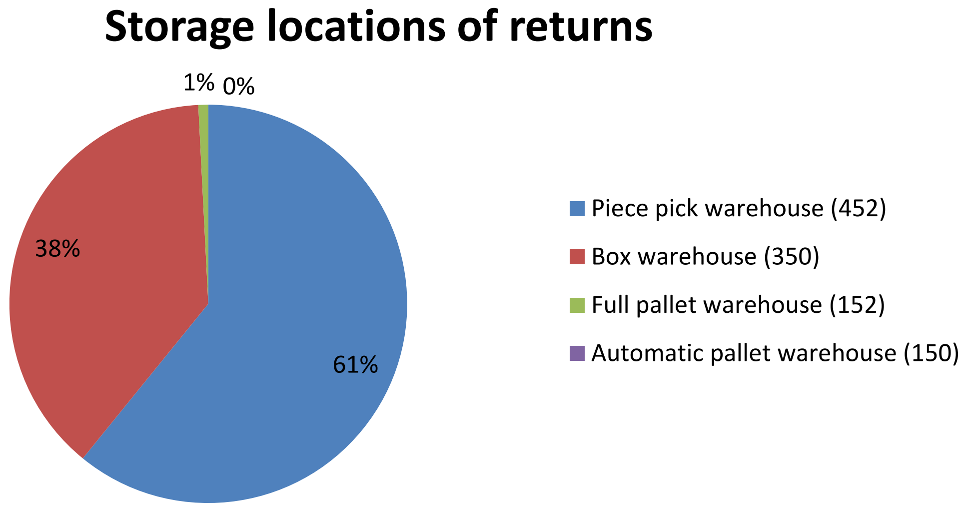


Figure 3.13 – Percentage of storage locations of returns

3.3.4 Own production

12% of all records are finished goods from own production. Recall that most of the finished goods from own production are stored outside and that the packaging line is excluded. This explains the low percentage of 12. Finished products from own production are most of the time checked directly when they arrive at the goods receipt building and thus do not follow the FIFO-rule. This is done because products from own production have short check times.

3.4 Conclusion

This section provides short answers on the formulated research questions.

2. <u>What is the current situation of the inbound process?</u>

There are four different flows of incoming products: finished goods from the production departments in Hardenberg, products from other factories of Wavin throughout Europe, trade items from external suppliers, and returns from customers & depots. The inbound process begins when trucks arrive at the distribution centre. Trucks are unloaded and products are stored in the receive area. When products are ready to be checked, the products are moved from the receive area to the check area. In the check area, products are registered in the ERP-system and checked on quality and quantity. After that, products are moved to their storage destination. The inbound process ends when the products are available for order picking.

2.1. How is the logistics process organized, and what are the stakeholders?

Different stakeholders of the project are: Demand & Supply department, Sales & Marketing department, and the Logistics department. The Demand & Supply department influences the incoming deliveries. Sales & Marketing make agreements about delivery dates with customers and therefore products must be in stock as soon as possible.

The Logistics department is the main stakeholder of the project. The general steps that a product follows in the distribution centre are: goods receipt, storing, staging, and loading.

2.2. What are the activities of the goods receipt team?

The activities of the goods receipt team can be divided into three main activities: receive, check, and put away. The goods receipt team is not fully responsible for the put away activity since the products are put in stock by the warehouse team.

2.3. What are the largest suppliers?

Based on an analysis of 13 weeks, week 36-48 in 2015, we conclude the following things for the incoming products of the inside warehouse (recall that the packaging line is excluded in this analysis):

- The largest number of incoming products (52%) comes from other factories of Wavin throughout Europe.
- 23% comes from external suppliers. In total, 78 different external suppliers delivered products in the analysed period.
- 13% are returns from customers and stock movements from depots.
- 12% comes from the own production plants in Hardenberg.
- The storage locations are: 50% is stored in the box warehouse, 23% in the full pallet warehouse, 20% in the piece pick warehouse, and 7% is stored in the automatic pallet warehouse.

This chapter provides information about the current situation of the inbound process. This chapter describes the main stakeholders of the project, the activities of the goods receipt team, and the largest suppliers. Chapter 4 describes the current performance of the inbound process.

4 Current performance

Chapter 3 provides information about the current situation of the inbound process. This chapter describes the current performance of the inbound process. In Section 4.1 we describe performance indicators that are currently in place and measured. We identify different problems that result in underperformance of the inbound process in Section 4.2. In Section 4.3 we give the conclusions of this chapter.

4.1 Performance indicators

Wavin uses different Performance Indicators (PIs) to monitor processes. The only PI that is directly related to the inbound process is the productivity of the goods receipt team. Other PIs that are measured within the warehouse are:

- Stock reliability: to check if the number of products in the data is the same as the actual stock.
- Productivity: the number of picks per man-hour for the inside/outside warehouse.
- Failures: this are reported faults, could be an error in picks or a shortage.
- External service rate: the percentage of deliveries that are in-full and on-time delivered to customers.

<u>Productivity of the goods receipt team</u>

The productivity of the goods receipt team is measured by the number of picks per man-hour. Recall that one pick means a unique product with a given quantity that gets its own destination in one of the storage types. All man-hours spent in the receive and check activity in one week are added together. The total picks per week are divided by the total hours spent, and results in the average picks per man-hour in a certain week. The target is 8 picks per man-hour. Even though the average productivity increased from 5.94 picks per man-hour in 2014 to 6.64 picks per man-hour in 2015, the target of 8 picks per man-hour has never been reached. The maximum value in 2015 was 7.31 in week 37. One of the reasons that the target has never been reached, is that part of the production is outsourced to the production plant of Wavin in Poland. The consequence of outsourcing the production is that there are much more products that follow the general inbound process instead of being handled at the packaging line. The goods receipt team has too little space to handle products efficiently and that result in a lower productivity. Before outsourcing, the productivity level was close to 8 picks per man-hour. This research project contributes to return to an average productivity of 8 picks per man-hour. Figure 4.1 gives an overview of the productivity in 2014 and 2015.

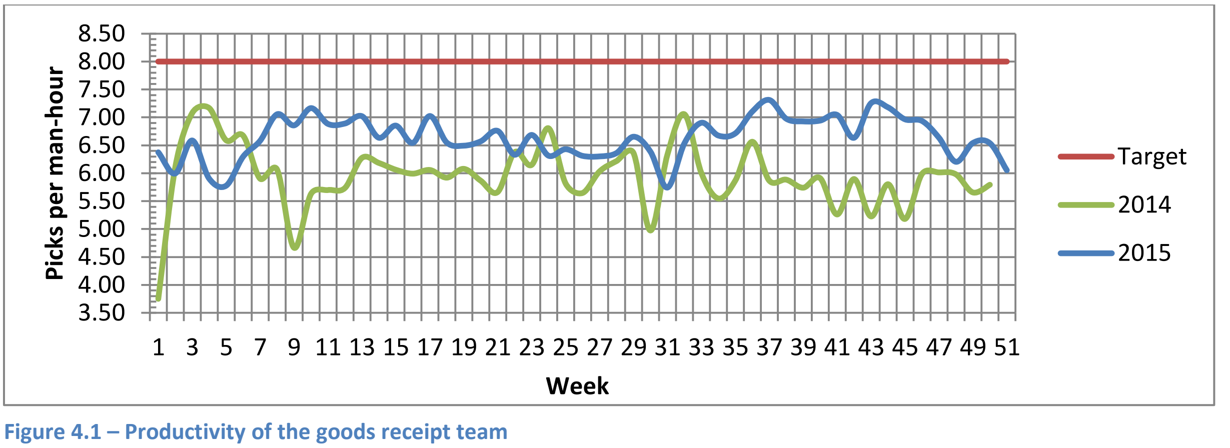


Figure 4.1 – Productivity of the goods receipt team

Self-assessments

The logistics department also executes self-assessments. These tests are obligated by the parent company Mexichem. One of the self-assessments measures the lead time between the arrival day of a product and the day when the product is checked. The maximum allowed duration is 3 working days. The arrival day of most products is entered manually in the ERP-system. Scanned full pallets from internal suppliers of Wavin do not have a reliable arrival day in the ERP-system. The pallets are scanned when the check activity starts and the ERP-system registers this day as 'arrival day'. It could be that the duration of a product is one working day while the product is already unloaded a few days ago. This error is ignored in the measurement.

Thus, the only performance indicator that is directly related to the inbound process is the productivity of the goods receipt team. This results in a lack of visibility which we describe in Section 4.2.1. Other important measures such as the dock to stock time and the progress of the check activity are currently not used. Section 5.2 describes other indicators to measure the performance of the inbound process.

4.2 Problems of the inbound process

We identify different problems that result in underperformance of the inbound process:

- Section 4.2.1 describes the topic performance monitoring. The only performance indicator that is directly related to the inbound process is the productivity indicator. Besides that, there are some issues with the productivity indicator that may lead to incorrect decision making by the management team.
- Section 4.2.2 describes the planning of incoming deliveries. Although procurement planners try to create a constant workflow for the goods receipt team, the planning of incoming deliveries is not efficient. Procurement planners plan deliveries by intuition and the planning is not based on historical data or in accordance with the goods receipt team. Goods receipt operators do not know exactly when trucks arrive at the distribution centre and just unload trucks when they arrive.
- Section 4.2.3 describes the staff capacity. There is insufficient staff capacity to perform the inbound process efficiently. Moreover, the capacity of the goods receipt team is not related to the number of incoming products and there is no flexible workforce during peak hours.
- Section 4.2.4 describes the available space. Currently there is insufficient space to store all products efficiently before the products are available for order picking. Pallets are moved frequently within the warehouse, resulting in a lot of traffic with forklifts in a confined area.
- Section 4.2.5 describes the topic quality and checking. The check activity is the most labour intensive activity of the inbound process. Lots of products must be repacked on other pallets due to the warehouse design. Besides that, the check time differs a lot per supplier. Correct deliveries are essential to process the products quickly and accurately.
- Section 4.2.6 describes the topic from checked to stored. 93% of the products are first stored on an interim storage place after the check activity. This results in long put away times.

4.2.1 Performance monitoring

Section 4.1 describes that currently only one performance indicator is directly related to the inbound process. This performance indicator measures the productivity by the number of handled 'picks' per man-hour in a certain week. The productivity indicator is insufficient to measure the performance of the inbound process. It just gives an indication of the relation between the used workforce and the workload in a certain period, and results in a lack of visibility. There are some issues with the current performance indicator that may lead to incorrect decision making by the management team:

- All man-hours spent in the receive activity and check activity are added together to calculate the performance indicator. Also the man-hours of the operators who are not directly involved with the general check activity are included in this indicator. When one of these operators is absent, this results in a higher productivity rate. One of the reasons is that the operator that handles the returns usually has a lower productivity rate due to long check times. Besides that, the operator that handles other materials such as office supplies and raw materials has other working activities and thus handles fewer products.
- When scheduling the staff capacity, the number of (expected) incoming products is not taken into account. This results in fluctuations of the productivity measure.
- The number of handled 'picks' in a certain week is derived from the wrong variable in the ERP-system. It is derived from the variable confirmation date instead of the real check date. Thus, the man-hours are spent in the receive activity and check activity and the number of 'picks' are the ones in the put away activity. It happens frequently that products are checked on Friday while the put away activity is done on Monday. This results in 'picks' that are counted in the wrong week.
- Another thing that happens is that the productivity in a certain period is high, while operators are busy with checking products that are unloaded at the distribution centre a few days ago. This results in long dock to stock times and the management team needs to take action.

Given the above mentioned points, there is a lack of visibility in the actual performance of the inbound process when only using the productivity indicator. Section 5.2 provides new performance indicators to measure the performance of the inbound process.

Conclusions about performance monitoring

- The productivity indicator includes also the man-hours of the operators who are not directly involved with the general check activity. When one of these operators is absent, this results in a higher productivity rate.
- When scheduling the staff capacity, the number of (expected) incoming products is not taken into account. This results in fluctuations of the productivity measure.
- The number of handled 'picks' in a certain week is derived from the wrong variable in the ERP-system.
- It happens that the productivity in a certain period is high, while operators are busy with checking products that are unloaded at the distribution centre a few days ago. This results in long dock to stock times and the management team needs to take action.

4.2.2 Planning of incoming deliveries

In the current situation it is not known when trucks arrive at the distribution centre. One of the goods receipt operators just stops with the check activity and unloads the truck. Suppliers do not have a fixed time window in which they deliver their products. Although some suppliers do have a fixed delivery day, the goods receipt team does not use this information to schedule their activities. Procurement planners try to create a constant workflow for the goods receipt team by making appointments about fixed delivery dates with most of the large suppliers. According to one of the procurement planners, the division over the week is not based on historical data.

To get an impression of how other companies deal with planning of incoming deliveries, we have visited the distribution centre of Technische Unie in Alphen aan den Rijn. Technische Unie is the largest technical wholesaler within the Netherlands and a customer of Wavin. During the company visit, we have discussed with the coordinator of logistics arrival & control how Technische Unie plans their incoming deliveries. At the distribution centre of Technische Unie, the distribution of incoming deliveries over the week is also done by intuition and not based on historical data. Almost all suppliers of Technische Unie do have a fixed delivery day. The difference with Wavin is that some suppliers also have a fixed delivery time.

Furthermore, the reliability (or on time performance) of suppliers of Technische Unie is continuously measured. The coordinator of Technische Unie noticed that about 40% of the deliveries arrive at the agreed delivery date. Currently suppliers are not punished when they deliver late. At the distribution centre of Technische Unie, arrivals of suppliers with fixed delivery times have priority to arrivals without fixed delivery times. This priority rule is only used when suppliers with fixed delivery times arrive on time.

Another thing we have discussed during the company visit is the difficulty of providing a constant workflow, since there are several factors that influence the handling time of deliveries. It could be that one full truck load from a supplier is handled faster than just one mix-pallet with different products. Therefore, correct deliveries are essential to process the products quickly and accurately.

Turning back to Wavin, factors that influence the handling time of deliveries are:

- Volume
- Number of pallets
- Number of order lines
- Number of products
- Number of mixed pallets
- Number of pallets that must be repacked
- Quality of the packing material
- Visibility of the product numbers
- Correct packing lists/orders

We have measured the exact arrival times of trucks for a period of two weeks because there is no data available in the ERP-system. Figure 4.2 shows the distribution of the delivery times. 85.7% of the deliveries arrive at the distribution centre during the first shift of the goods receipt team (from 6:00 AM to 2:00 PM). From 7:00 PM to 10:00 PM there are no arrivals (second shift is from 2:00 PM to 10:00 PM). The arrival pattern of deliveries at Technische Unie is also discussed during the company visit. According to the supply chain efficiency manager of Technische Unie, the peak of incoming deliveries at their distribution centre is also during the morning. In the afternoon and evening almost no trucks come to the distribution centre in Alphen aan den Rijn to unload their products.

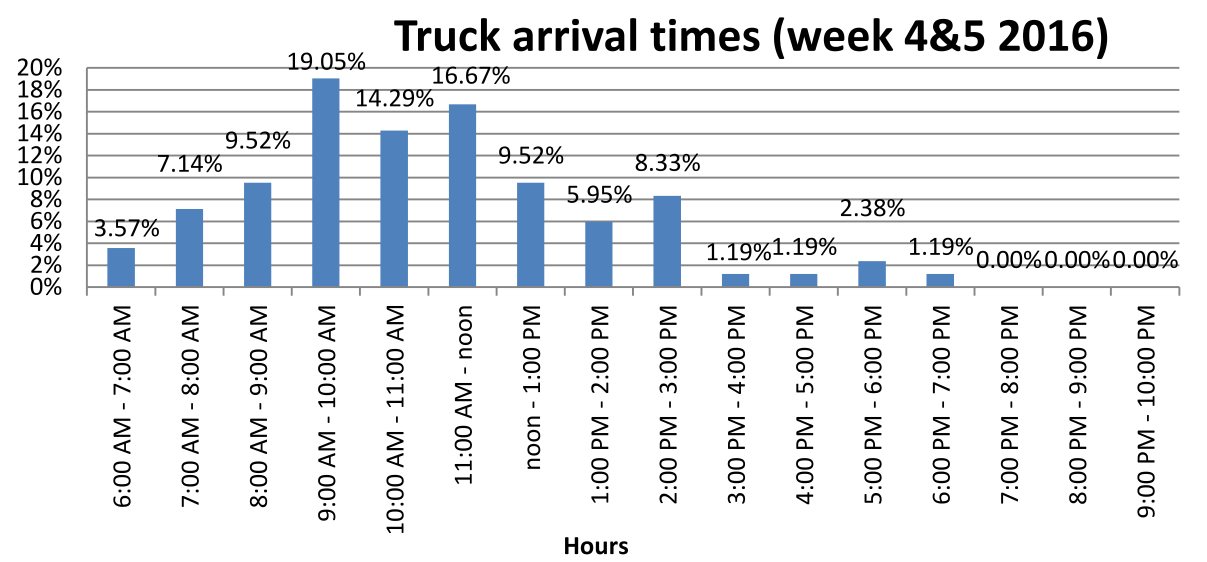
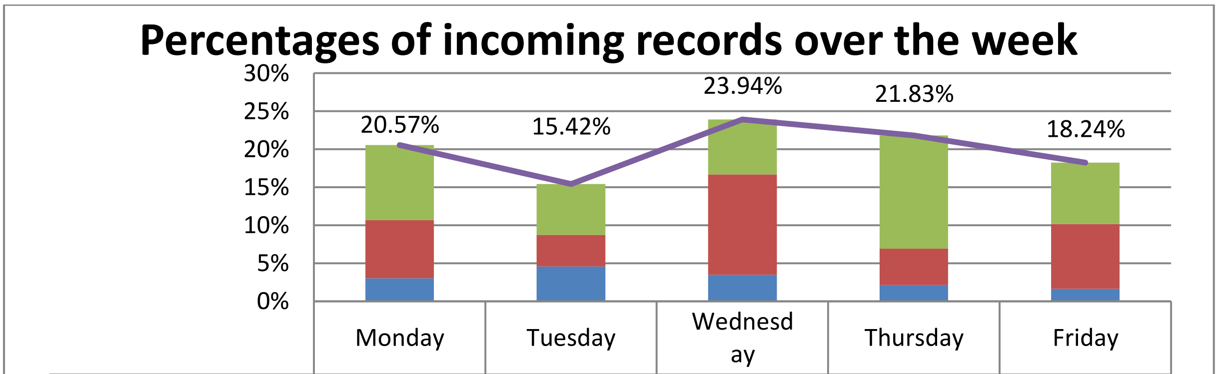


Figure 4.2 - Timeline of incoming deliveries

To give some idea about the deliveries at the distribution centre of Wavin, we show the distribution of incoming records over the week in Figure 4.3. The figure shows the variability over the week. The records are obtained from the data analysis of week 36-48 in 2015 (see also Section 3.3). Returns, and deliveries from internal supplier Buk Poland are excluded in the figure, because these records do not have a reliable delivery day in the data. Recall that it could be that the incoming records on Wednesday (23.94% of the total records) are handled faster than the records on Tuesday (15.42% of the total records) due to incorrect deliveries or records with long check times.



	Monday	Tuesday	Wednesday	Thursday	Friday
Internal suppliers	9.89%	6.70%	7.25%	14.89%	8.10%
External suppliers	7.66%	4.15%	13.21%	4.81%	8.50%
Own production	3.02%	4.57%	3.48%	2.12%	1.64%
Total	20.57%	15.42%	23.94%	21.83%	18.24%

Figure 4.3 - Division of incoming records over the week

Internal suppliers

Almost all internal suppliers must deliver products at the distribution centre on fixed days. The high percentage from internal suppliers on Thursday (see Figure 4.3) comes from Wavin plants in Denmark and Germany. Some internal suppliers, such as Buk Poland, deliver daily to the distribution centre but are excluded in the analysis.

External suppliers

The largest external suppliers have fixed delivery days. When suppliers have two fixed delivery days these days are spread over the week, for example Tuesday and Friday. Almost all small external suppliers deliver their goods more or less at random. When analysing the number of records from external suppliers, we see a high peak at Wednesday while the number of different suppliers is not so high on Wednesday (see Figure 4.3 and Table 4.1). The largest external supplier, Nyloplast, is for 50% responsible for the records from external suppliers on Wednesday. Supplier Georg Fisscher has a fixed delivery day on Thursday while they actually deliver about 85% of their products on Wednesday. This is 15% of all incoming records from external suppliers on Wednesday. The reason that these deliveries are usually one day earlier, is that the trucks also drive along the distribution centre of Wavin in Twist Germany before they arrive at the distribution centre in Hardenberg. One of the procurement planners said that this is a kind of safety buffer to ensure that deliveries do not arrive too late. Friday is the day when the most different external suppliers come to the distribution centre to unload their products. Thus, operators are disturbed more frequently on Friday to unload.

	Monday	Tuesday	Wednesday	Thursday	Friday
Number of different external suppliers in week 36 to week 48 of 2015	38	41	37	35	52

Table 4.1 - Number of different external suppliers per day

Own production

Products from own production are most of the time checked directly when they arrive at the goods receipt building, and thus do not follow the FIFO-rule. Most of the incoming products are from the special products factory. The most products arrive at the goods receipt building on Tuesday, and the smallest numbers of products arrive on Friday.

Returns

It is difficult to conclude to give a distribution of the incoming returns over the week. The dates in the ERP-system are not reliable since these dates are the days when the staff member begins with the checking part. Thus, it is not the day when the returns are delivered at the distribution centre. Truck drivers take returns from depots back when they deliver a shipment to these depots. Therefore the distribution over the week is not included in the analysis.

Conclusions about the planning of incoming deliveries

- Procurement planners try to create a constant workflow for the goods receipt team based on their own skills and not on historical data.
- 95.2% of the deliveries are unloaded at the distribution centre before 4:00 PM.
- There are several suppliers that structurally do not deliver products on the agreed delivery dates.

4.2.3 Staff capacity

In total there are six employees directly involved in the inbound process (receive, check and part of the put away activity). The man-hours of these six employees are used to calculate the productivity of the goods receipt team (see also Section 4.1).

One of the six employees is the point of call for all incoming products. This operator handles all kind of incoming delivery issues and works daily from 7:30 AM to 4:00 PM. The purchase and the sales department contact him for information about deliveries. Forwarding trucks with materials for the factories, and handling deliveries with office supplies are also daily tasks of this operator. The operator has its own office within the goods receipt hall. The second operator is responsible for handling all returns. The operator has its own working area to treat returns. The working hours of this operator are from 7:30 AM to 4:00 PM.

A team of four operators, in two shifts of two persons, handles regular deliveries. The first shift is from 6:00 AM to 2:00 PM and the second shift from 2:00 PM to 10:00 PM. These shifts are similar to the shifts for the rest of the inside warehouse team. The rest of the warehouse team is responsible for the pick, pack, ship, and part of the put away activity. The goods receipt operators are involved with the receive, check, and part of the put away activity. Once the goods receipt operators put a pallet on one of the interim storage places or on the automatic conveyer the put away activity is ended for them.

In busy periods the goods receipt team also works on Saturday. Sometimes the warehouse staff help with the inbound process, which consist of forklift handling such as unloading trucks or moving pallets between interim storage places. Not every employee can do the check activity, so when one of the operators is absent there is no direct replacement. The reason is that the check activity requires skills that not every warehouse operator have, and therefore most of the time there is no direct replacement when one of the operators is absent. There is only back up in case of emergency and during holiday.

Conclusions about the staff capacity

- In total there are six employees directly involved in the inbound process. From Monday until Friday (6:00 AM – 10:00 PM) there are constantly two operators for the receive activity and the check activity. From 7:30 AM to 4:00 PM there are two other operators working, one treats the returns and the other one is the point of call for all incoming deliveries.
- The capacity to perform the inbound process is insufficient to handle products efficiently. This results in much waiting time.
- When an operator is absent he is not always replaced by another employee, because not all warehouse operators have skills to execute the check activity. When one of the other operators helps the goods receipt operators, the operator executes other tasks such as moving pallets from the receive area to the check area. There is only replacement in case of emergency or during holiday.

4.2.4 Available space

There is insufficient space in the check area to store all the incoming products. Therefore, products are first stored under a shelter roof after they are unloaded. This is the black rectangle, called receive area in Figure 4.4. After the receive activity, the products (mostly pallets) are moved to the check area. Returns are moved to another check area.

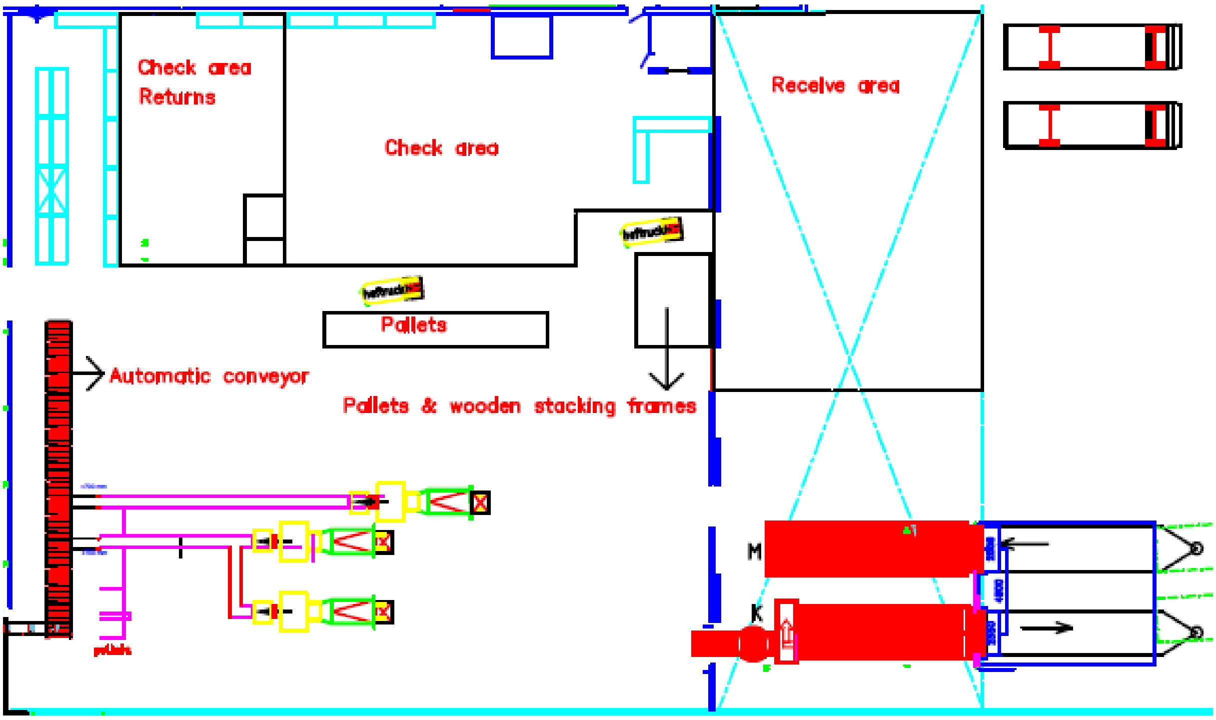


Figure 4.4 - Overview of the goods receipt hall

When the check activity is finalized, the products are moved dependent on their destined storage location. Products that go to the automatic pallet warehouse are put on the automatic conveyor, and all other products are moved to an interim storage place within the warehouse. Within these steps there is a lot of traffic in a confined area. One pallet that goes to the full pallet or box warehouse (73% of the scope) is moved at least five times by a forklift before the pallet is available for order picking.

Space in the receive area

After products are unloaded, they are stored in the receive area and are waiting to be checked. This is an open area with a shelter roof. When a full truck load from Poland (almost every day) arrives it contains about 60 pallets. This consumes a lot of space in the receive area. There are about 120 pallets places in the receive area. In an ideal situation these pallets can be stacked with a maximum of 2 pallets high, resulting in a maximum storage for 240 pallets. In reality 240 pallets are never stored in the receive area because a lot of incoming pallets or mesh boxes cannot be stacked.

Currently about once a week deliveries (mostly full truck loads, e.g. from Buk Poland) are unloaded and stored on staging areas in the distribution hall of the warehouse. This is done because the receive area is full and the pallets cannot be stored outside. This is not an ideal situation because these staging areas cannot be used by the warehouse operators that make the shipments clear for outbound deliveries. This results in interaction between inbound and outbound deliveries.

Space in the check area

When products can be checked they are moved from the receive area to the check area with the use of a forklift. As already mentioned, the check area for returns is separated from the check area for regular products. The space utilization in the check areas is very high with a lot of traffic. This is a considerable risk in terms of safety. The check areas consist of many objects that require space:

- An office for the archive of already checked packing lists.
- An office for the goods receipt operators.
- Waste bins for plastic and carton.
- Pallets (also with collars) that are needed to fit the products within the warehouse.
- Racks to store several incoming deliveries, such as office supplies.

Moreover, about 60% of the goods receipt hall is used for the packaging line. Research is already done for the relocation of the packaging line from the goods receipt hall to the injection moulding factory. Based on a list of requirements, a business case is made with three options. The option with the lowest return on investment is 4.1 years while the maximum return on investment at Wavin is 3 years. Therefore, the management team decides to reject the relocation.

Space on the interim storage areas within the distribution hall

When products are checked, the put away activity is dependent on their destined storage locations. Products that go to the automatic pallet warehouse are put on the automatic conveyor (7% of the records). Products that go to the piece pick warehouse are put on an interim storage place which has sufficient space (20% of the records). Most of the time, different products are put on one pallet and moved to this interim storage place in the distribution hall.

Pallets that go to the full pallet or box warehouse (73% of the records) are put on another interim storage place within the distribution hall. When the interim storage place is full, the forklift driver puts the checked pallets on one of the staging areas. This lead again to intertwined traffic between inbound and outbound processes.

Conclusions about available space

- Pallets that must be stored in the full pallet or box warehouse (73% of the scope) are moved at least five times by a forklift before they are on location.
- There is a lot of traffic with forklifts in a confined area. This results in safety issues.
- Incoming deliveries are about once a week placed on staging areas. This results in interaction between inbound and outbound deliveries.

4.2.5 Quality and checking

The check activity is the most labour intensive activity of the inbound process. There are multiple factors that influence the check time. These can be split into internal and external factors. An example of an external factor is that products do not have any label or article number. Correct deliveries are essential to process the products quickly and accurately. An example of an internal factor is the storage location. Due to the design of the storage locations, all products that are not stored in the piece pick warehouse must be stacked on a special Wavin Hardenberg pallet.

This requires much manual handling time, since the design of this pallet is unique. The maximum height of the pallet including the products is 120 centimetres. Therefore it is most of the time not possible to stack the delivered pallet onto the Wavin Hardenberg pallet. See Section 3.2.2 for more information about the Wavin Hardenberg pallet.

During observations we noticed that operators work in the sequence of the GETI-list. This list contains information about the delivery: order numbers, article numbers, number of products, destined storage types, storage unit et cetera. Together with the packing list, the GETI-list is used to check the order. The pallets with products are spread within the check area (see Figure 4.4) and operators do not follow the sequence in which they are stored. This results in much walking time by searching for products. Furthermore, operators do not always inform logistics specialists when products are damaged, missing, or delivered in other quantities than ordered. Another problem is that operators do not always follow the FIFO-rule. Only the delivery day is noted on the pallets and not the exact delivery time, so products are only checked in the sequence of the delivery day. Besides that, there are priority cases due to out of stocks or delayed delivery of products. Also products from own production are mostly checked directly. When operators are busy with checking one delivery they are frequently disturbed for unloading other deliveries. This is not preferable since operators cannot concentrate on one delivery. This results in extra handling time and possible errors.

Conclusions about quality and checking

- The operators work in the sequence of the order list and this results in much walking time by searching for products.
- Operators do not always inform logistics specialists when products are damaged, missing, or delivered in other quantities than ordered.
- The FIFO-rule is only used on daily base. Moreover, (delayed) deliveries with out of stocks and products from the own factories are checked directly.
- Operators are frequently disturbed when checking a delivery for unloading of other deliveries. This results in extra handling time and possible errors.

4.2.6 From checked to stored

Besides the waiting time between the receive and the check activity, there is much waiting time encountered after the products are checked correctly. When products are checked, they are not immediately put in stock and therefore the put away activity includes much waiting time. Based on data from week 36-48 in 2015 the average put away time is 4:40:41 working hours. This has several reasons that we describe individually in this section.

<u>Automatic conveyer</u>

Most of the time, one of the goods receipt operators moves the checked products to one of the interim storage places (93% of the records) or put them on the automatic conveyer when the destination is the automatic pallet warehouse. Originally this conveyer was also designed to transport the pallets for the full pallet and box warehouse, but in practice this does not work. One of the reasons is that part of the production is outsourced to the production plant of Wavin in Poland.

The consequence of outsourcing the production is that there are much more products that follow the general inbound process. 79% of the records from Poland have a storage destination in the full pallet or box warehouse and the conveyer system is not designed to move such number of pallets from the check area to the end of the automatic conveyer. Operators take these pallets from the end of the automatic conveyer at height (around 3 meter) with a forklift, and move them to the right pick/drop point at the front-end of an aisle. The pallets must be picked at height because the conveyer crosses the outbound conveyer from the automatic pallet warehouse. Employees experience this as an inefficient situation and therefore pallets are moved by a goods receipt operator to an interim storage place within the distribution hall. On this interim storage place pallets are stored for a long time.

As already mentioned, when this interim storage place is full, the forklift driver puts the checked pallets on one of the staging areas. The distribution planners ignore the fact that not all staging areas are available and just schedule the outbound deliveries based on their staging design. The consequence is that the warehouse team must search for other space within the warehouse to collect deliveries. Another problem is that the packaging line is connected to the conveyer. When the conveyer is fully loaded with pallets, the working activities of the operators at the packaging line are blocked.

<u>Capacity within the aisles</u>

From 6:00 AM to 10:00 PM there are three or four man-up forklift cranes used within the aisles of the box warehouse. From 7:30 AM to 4:00 PM there is one operator that handles all the inputs and outputs for the full pallet warehouse. The first priority of the operator is to empty the pick/drop points with a man-up forklift within the aisles of the box warehouse. If these are empty, the operator drives on a forklift to fill the drop points with pallets from the interim storage location on the warehouse floor. If this interim storage place is also empty, the operator drives to the goods receipt hall to pick up pallets directly from the operators who fulfil the check activity. In practice this almost never happens, because most of the time there are pallets stored on the interim storage location or in the pick/drop points.

The operator that is responsible for moving the picks from the pick points to the distribution hall also places pallets from the interim storage location to the drop points. This is more or less done at random and based on the intuition of the operator.

<u>Confirmation patterns</u>

Another issue is the pattern of confirmation. Figure 4.5 shows the confirmation times of incoming products in the full pallet and box warehouse during week 36-48 of 2015 and Figure 4.6 gives an overview of all input, output, and replenishment operations within the full pallet and box warehouse. Almost 40% of the inputs are confirmed on their destined location between 7:00 PM and 10:00 PM. In the morning from 6:00 AM to 9:00 AM there many output operations. At 9:00 AM and at 6:00 PM the employees have a break of 30 minutes and at 12:00 PM a break of fifteen minutes. This results in the low output picking frequency at these times.

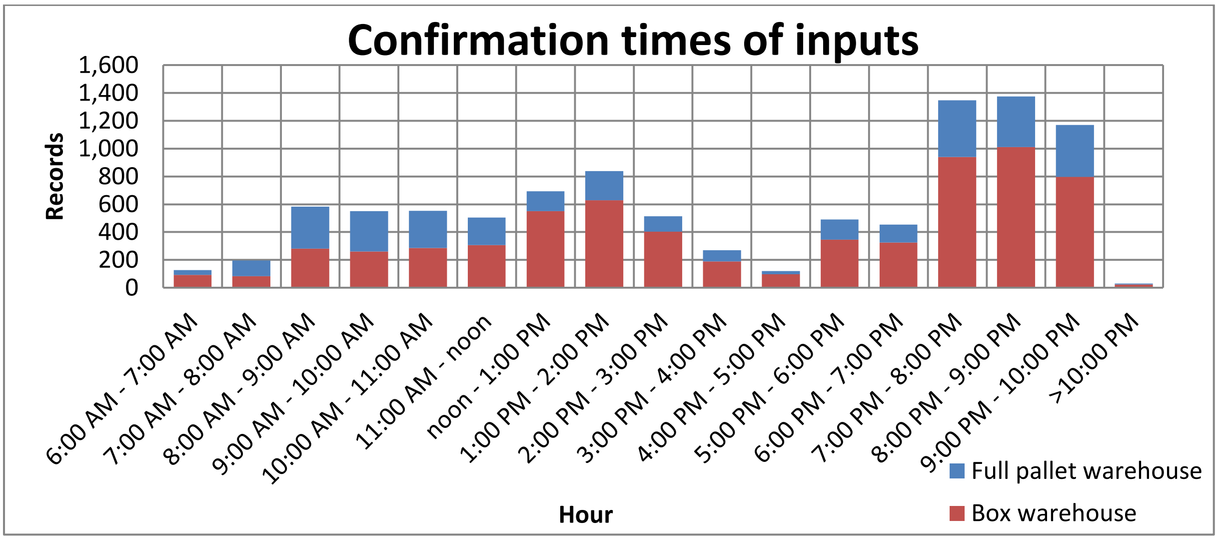


Figure 4.5 - Confirmation times of inputs

During the day several runs with orders are executed. A run contains orders that are already entered in the ERP-system and can be picked at that moment. For example: orders for the 24-hours flow that are entered in the ERP-system before 10:00 AM are listed in the run of 10:00 AM. At 1:00 PM there is no execution of a run because this is the last working hour of the first shift. This explains the low number of total picks between 1:00 PM and 2:00 PM. The runs for replenishment operations are executed manually and the first run is done at 2:00 PM during the beginning of the second shift. A lot of replenishment picks are done during the evening when the most output picks are finalized.

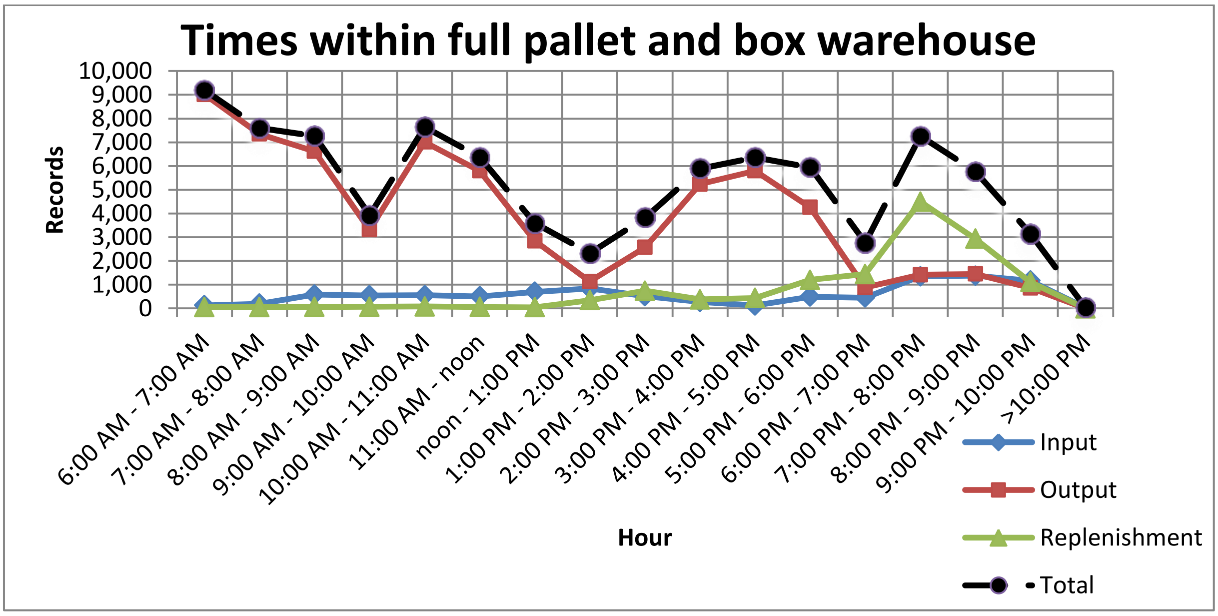


Figure 4.6 - Confirmation times inputs/outputs/replenishment

Recall that the number of input records is lower than the number of output records, because one pallet for the box warehouse can result in multiple output picks. Therefore the total output records are almost 7 times larger than the input records. The patterns are discussed with the warehouse lead manager and the two team leaders and they verify the patterns. One of the team leaders said that the priority for the warehouse operators is as follows: output picks > replenishments > input picks. The reason is that trucks must be loaded with products within fixed time windows. Therefore outputs have priority to inputs, and a lot of inputs are confirmed on their destined location in the evening.

One of the team leaders noticed that it takes too much time to switch the digital equipment continuously from put away tasks to picking tasks. Operators at the man-up forklift must switch their digital equipment from output picks to input picks. A test is done, and it requires 22 seconds to switch the digital equipment from output to input and back. Furthermore, it depends per operator how much picks per man-hour are done. The team leader said that outbound deliveries were loaded too late when inputs are put in stock earlier. Another problem is that not all aisles (mostly 3 or 4 out of 10 aisles in the box warehouse) are continuously occupied by the cranes. This can result in full pick/drop points at unoccupied aisles and empty pick/drop points at occupied aisles.

Besides that, there is a lot of fluctuation in the throughput per time unit from the check area to the interim storage locations. Sometimes the goods receipt team puts 20 pallets in 30 minutes from the check area to the interim storage location, while the other time they deliver nothing during several hours. This is also one of the reasons that the conveyer system does not work optimally. The conveyer does not have a large buffer and when the conveyer is fully loaded, the activities of the packaging line are blocked.

Conclusions about from checked to stored

- The conveyer is not used to transport pallets destined for the full pallet and box storage locations from the goods receipt hall to the distribution hall. Operators from the goods receipt team brings checked pallets to an interim storage place with the use of a forklift.
- The warehouse team has the following priority: output > replenishment > input. Therefore, a lot of inputs that are already checked have much waiting time before they are available for order picking. Based on data from week 36-48 in 2015 the average put away time is 4:40:41 working hours.
- Almost 40% of the products are confirmed on their destined location after 7:00 PM because the warehouse team cannot guarantee that outbound deliveries are on time when more products are put away earlier. Switching the digital equipment from output to input and back requires every time 22 seconds.
- There is a lot of fluctuation in the throughput per time unit from the check area to the interim storage locations. Sometimes the goods receipt team puts 20 pallets in 30 minutes from the check area to the interim storage location, while the other time they deliver nothing during several hours. This is also one of the reasons that the conveyer system does not work optimally. The conveyer does not have a large buffer and when the conveyer is fully loaded, the activities of the packaging line are blocked.

4.3 Conclusion

This section provides short answers on the formulated research questions.

3. <u>What is the current performance of the inbound process?</u>

Currently the goods receipt team cannot reach the goal of 8 picks per man-hour. The maximum picks per man-hour in 2015 were 7.31 in week 37; hence the target has not yet been reached. The average picks per man-hour in 2015 were 6.64. Recall that one pick means a unique product with a given quantity that gets its own destination in one of the storage types.

We indicate several problems that result in underperformance of the inbound process:

- Performance monitoring, the only performance indicator that is directly related to the inbound process is the productivity indicator. This results in a lack of visibility.
- Planning of incoming deliveries, although procurement planners try to create a constant workflow for the goods receipt team, the planning of incoming deliveries is not efficient.
- Staff capacity, there is insufficient staff capacity to perform the inbound process efficiently.
- Available space, there is a lot of traffic in a confined area that lead to safety issues.
- Quality and checking, lots of products must be repacked on other pallets due to the warehouse design. Besides that, operators work in the sequence of the order list that results in much time used for searching products.
- From checked to stored, there is much waiting time when products are already checked and can be put in stock.

3.1. Which performance indicators are currently in place and measured?

The only performance indicator that is directly related to the inbound process is the productivity of the goods receipt team. The productivity of the goods receipt team is measured by the number of picks per man-hour. Other important measures such as the dock to stock time and the progress of the check activity are currently not used. In Section 5.2 we describe other PIs to measure the performance of the inbound process.

3.2. What are the problems of the inbound process?

We identify different problems that result in underperformance of the inbound process. The only performance indicator that is directly related to the inbound process is the productivity indicator. This results in a lack of visibility. Besides that, there are some issues with the productivity indicator that may lead to incorrect decision making by the management team.

Although procurement planners try to create a constant workflow for the goods receipt team, the planning of incoming deliveries is not efficient. Procurement planners plan deliveries by intuition and the planning is not based on historical data or in accordance with the goods receipt team. Goods receipt operators do not know exactly when trucks arrive at the distribution centre and just unload trucks when they arrive. Furthermore, there is insufficient staff capacity to perform the inbound process efficiently. The capacity of the goods receipt team is not related to the (expected) number of incoming products and there is no flexible workforce during peak hours. Another problem is the available space in the receive area, check area, interim storage locations, and the pick/drop points. Pallets are moved frequently within the warehouse, resulting in a lot of traffic with forklifts in a confined area. Besides that, incoming deliveries are about once a week placed on staging areas. This results in interaction between inbound and outbound deliveries.

The check activity is the most labour intensive activity in the inbound process. Lots of products must be repacked on other pallets due to the warehouse design and the check time differs a lot per supplier. When the check activity is finished it takes on average 4:40:41 working hours (in week 36 to week 48 2015) before the products are available for order picking. Most of this time is waiting time in one of the interim storage locations.

This chapter gives useful information about problems that result in underperformance of the inbound process. Besides that, there is only one performance indicator that is directly related to the inbound process. We use the information from this chapter to provide possible improvements in Chapter 5.

5 Improvements

Chapter 4 describes problems that result in underperformance of the inbound process. Besides that, we found that only one performance indicator is directly related to the inbound process. This chapter provides possible improvements to optimize the inbound process. Moreover, we describe different performance indicators to give more visibility in the inbound process. Section 5.1 gives an overview of the problems that we solve. Section 5.2 presents different indicators to measure the performance of the inbound process. We provide information about an experiment in practice in Section 5.3. Section 5.4 describes a simulation model to show the importance of a predictable and even workflow. Section 5.5 describes how to solve the indicated problems. Finally, we give the conclusions of this chapter in Section 5.6.

5.1 Introduction

Chapter 4 identifies different problems that result in underperformance of the inbound process. We divide the problems into 6 main topics. Figure 5.1 gives an overview of the 6 problems and the relation with Sections 5.2 to 5.6. After the figure we explain the problems briefly and argue why we make different choices.

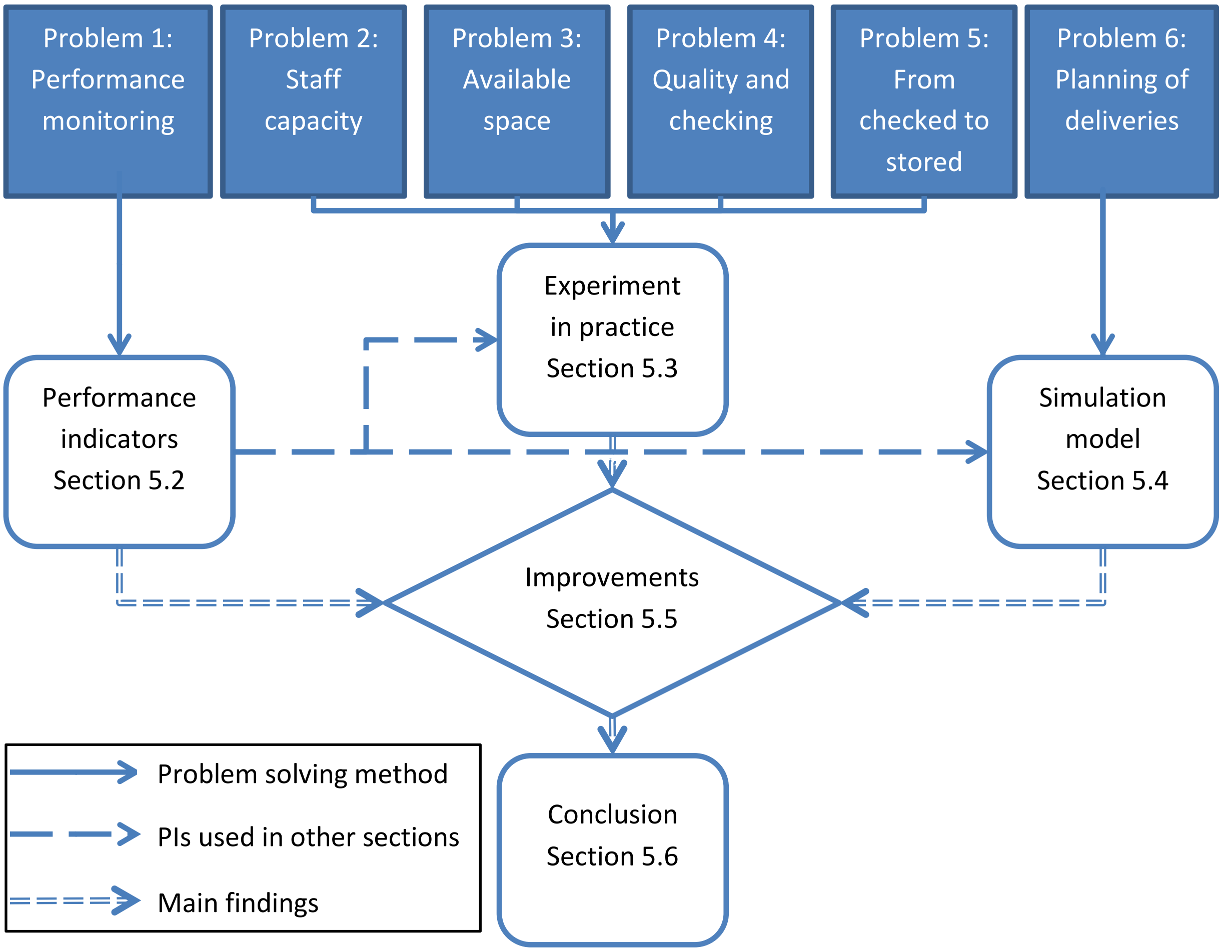


Figure 5.1 - Overview of the problems and the relation with the different sections

Problem 1 – Performance monitoring: There is only one performance indicator that is directly related to the inbound process. We solve problem 1 with the use of new performance indicators, as we describe in Section 5.2. We use the indicators to measure the interventions of the experiment in Section 5.3 and the simulation in Section 5.4.

We solve problems 2 to 5 through the use of an experiment in practice. We choose an experiment in practice because the results of the different interventions are directly visible for the warehouse operators. We want to involve all the warehouse operators within the project and with an experiment in practice we can convince the operators easier. It is also easier to emphasize the importance of an efficient inbound process. Besides the more psychological reasons, it is difficult to build a reliable simulation model due to the absence of data. Within the short time period it is hard to build a reliable simulation model that is able to test the interventions related to problems 2 to 5. It is for example difficult to model the staff capacity in a simulation, and obtain reliable outcomes. Thus, to solve problems 2 to 5, we perform an experiment in practice instead of building a simulation model.

Problem 2 - Staff capacity: There is insufficient staff capacity to perform the inbound process efficiently. Moreover, the capacity of the goods receipt team is not related to the number of incoming products and there is no flexible workforce during peak hours. Section 5.3 describes several interventions with the staff capacity in practice.

Problem 3 - Available space: There is insufficient space to store all products efficiently before the products are available for order picking. Pallets are moved frequently within the warehouse, resulting in a lot of traffic with forklifts in a confined area. Besides that, inbound deliveries are frequently stored on staging areas, resulting in interaction with outbound deliveries. The experiment in practice, as we describe in Section 5.3, result in fewer space issues.

Problem 4 - Quality and checking: The check activity is the most labour intensive activity of the inbound process. Lots of products must be repacked on other pallets due to the warehouse design. Besides that, the check time differs a lot per supplier. Correct deliveries are essential to process the products quickly and accurately. Section 5.3 describes different interventions that result in faster check times.

Problem 5 - From checked to stored: 93% of the products are first stored on an interim storage place after the check activity. Besides that, the warehouse operators have more priority for picking outbound delivery than pallet retrieval. Almost 40% of the products are confirmed on their destined location between 7:00-10:00 PM and this results in long put away times. Section 5.3 describes an experiment in practice that result in faster put away times.

Problem 6 - Planning of incoming deliveries: Although procurement planners try to create a constant workflow for the goods receipt team, the planning of incoming deliveries is not efficient. The deliveries are not based on historical data, or in accordance with the goods receipt team. Section 5.4 describes a simulation model to show the importance of a predictable and even workflow. We choose to build a simulation model because it is hard to experiment in practice. The interventions that we test are complex to experiment in practice because Wavin has a lot of different suppliers. The interventions require new agreements with all suppliers and this is not possible within the short time period. Besides that, we first want to know the outcomes of a certain intervention before we recommend the intervention in practice.

5.2 Performance indicators

Chapter 4 describes that currently only one performance indicator is directly related to the inbound process. This performance indicator measures the productivity by the number of handled ‘picks’ per man-hour. The productivity indicator is insufficient to measure the performance of the inbound process. It just gives an indication of the relation between the used workforce and the workload in a certain period, and results in a lack of visibility.

Therefore we need new indicators to measure the performance of the inbound process. Section 2.2 provides a literature review about performance indicators of inbound processes. Table 5.1 gives an overview of the performance indicators that we analyse in this section. The performance indicators are divided in the dimensions: Time, Productivity, Quality, and Utilization. We define a product as a unique product with a given quantity that gets its own destination in one of the storage types. So when a mix-pallet contains 10 different products it results in 10 different outputs. We make this choice because this is equivalent to the available data. We describe the performance indicators briefly per dimension in Sections 5.2.1 to 5.2.4. We use the performance indicators in the experiment in Section 5.3 and the dock to stock time indicator in the simulation model in Section 5.4.

Dimension	Indicator	Definition	Nr.
Time indicators Section 5.2.1 Should be short	Dock to stock time	Lead time from product arrival to availability for picking	1
	Receive time	Lead time from product arrival to the beginning of the check activity	2
	Check time	Lead time to check a product	3
	Put away time	Lead time from the moment that a product is checked to when it is stored in its destined location	4
Productivity indicators Section 5.2.2 Should be high	Receive productivity	Number of products unloaded per man-hour	5
	Check productivity	Number of products checked per man-hour	6
	Check returns productivity	Number of returns checked per man-hour	7
	Put Away productivity	Number of products stored per man-hour	8
Quality indicators Section 5.2.3 Should be high	On-time performance	Ratio of deliveries that arrive on the agreed delivery date	9
	Check accuracy	Ratio of products checked correctly	10
	Put Away accuracy	Ratio of products stored in correct location	11
Utilization indicators Section 5.2.4 Should be low	Receive area utilization	Ratio of occupied space in the receive area	12
	Check area utilization	Ratio of occupied space in the check area	13
	Interim storage utilization	Ratio of occupied space in the interim storage zone	14

Table 5.1 - Overview of the performance indicators

5.2.1 Time indicators

Time indicators are important to indicate when the inbound process takes too much time. When the time indicators are too long, managers can decide to schedule for example more staff capacity. Figure 5.2 gives an overview of the time indicators. The interval in which we measure the dock to stock time is weekly. At the beginning of the week the dock to stock times of the products that are confirmed in the previous week are calculated. When a product is unloaded in week 1 and confirmed on location in week 2, the dock to stock time of this product is calculated at the beginning of week 3 and counted for week 2.

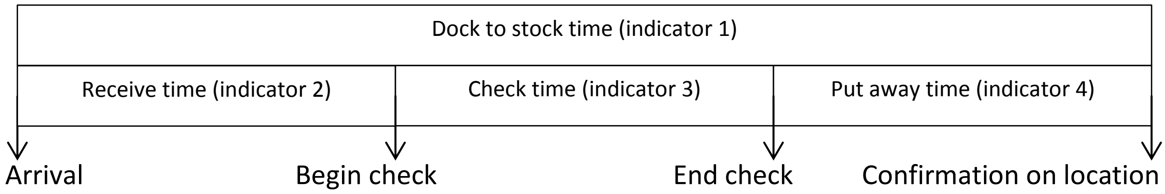


Figure 5.2 - Overview of the time indicators

<u>Dock to stock time (indicator 1)</u>

This indicator measures the lead time from product arrival until the product is available for picking.

$$Average\ dock\ to\ stock\ time = \frac{\sum_{i=1}^{N} Dock\ to\ stock\ time\ (i)}{N}\ hours$$

$$Dock\ to\ stock\ time\ (i) = Confirmation\ time\ on\ location\ (i) - Arrival\ time\ (i)$$

$$Product\ i = 1,2,3, \dots, N$$

The dock to stock time is an important indicator because it gives insight into the average lead time. When the dock to stock time in a certain week is considerably longer than in the previous weeks, we can use indicators 2 to 4 to identify the activity that result in long dock to stock times. When the interval of a week is insufficient to find the core problem, we can use a daily interval.

<u>Receive time (indicator 2)</u>

This indicator measures the average lead time from product arrival to the beginning of the check activity. Recall, that this indicator not only measures the unloading time, but also the waiting time before the products are checked.

$$Average\ receive\ time = \frac{\sum_{i=1}^{N} Receive\ time\ (i)}{N}\ hours$$

$$Receive\ time\ (i) = Begin\ of\ check\ time\ (i) - Arrival\ time\ (i)$$

$$Product\ i = 1,2,3, \dots, N$$

<u>Check time (indicator 3)</u>

The check time indicator measures the average check time of a product. This measure is useful to test individual suppliers on their performance. Correct deliveries are essential to process the products quickly and accurately. The indicator can be used when collaborating with suppliers in order to minimize check times.

$$Average\ check\ time = \frac{\sum_{i=1}^{N} Check\ time\ (i)}{N}\ hours$$

$$Check\ time\ (i) = End\ of\ check\ time\ (i) - Begin\ of\ check\ time\ (i)$$

$$Product\ i = 1,2,3, \dots, N$$

Put away time (indicator 4)

This indicator measures the lead time from the moment a product is checked to when it is stored in its destined location. When the put away times are considerably longer in a certain week, they can be split up dependent on their storage location. This means that the average put away times at each storage location are measured.

$$Average\ put\ away\ time = \frac{\sum_{i=1}^{N} Put\ away\ time\ (i)}{N}\ hours$$

$$Put\ away\ time\ (i) = Confirmation\ time\ on\ location\ (i) - End\ of\ check\ time\ (i)$$

$$Product\ i = 1,2,3, \ldots, N$$

5.2.2 Productivity indicators

Productivity indicators give insight into the handled products per man-hour at the different activities of the inbound process. The interval in which we measure productivity indicators is weekly. The productivity of checking returns is split from the general check productivity because checking returns takes usually more time than checking general products. Recall that a product is a unique product with a given quantity that gets its own destination in one of the storage types. The productivity of the receive activity (indicator 5) and the put away activity (indicator 8) is not separated in returns and general products because productivity is the same for all incoming products.

Receive productivity (indicator 5)

Number of products unloaded per man-hour.

$$Receive\ productivity = \frac{Total\ number\ of\ unloaded\ products}{Total\ man\ hours\ spent\ in\ the\ receive\ activity}\ products/man\_hour$$

Check productivity (indicator 6)

Number of products checked per man-hour.

$$Check\ productivity = \frac{Total\ number\ of\ checked\ products}{Total\ man\ hours\ spent\ in\ the\ check\ activity}\ products/man\_hour$$

Check returns productivity (indicator 7)

Number of returns checked per man-hour.

$$Check\ returns\ productivity = \frac{Total\ number\ of\ returns\ that\ are\ checked}{Total\ man\ hours\ spent\ for\ checking\ returns}\ returns/man\_hour$$

Put away productivity (indicator 8)

Number of products stored per man-hour.

$$Put\ away\ productivity = \frac{Total\ number\ of\ products\ that\ are\ put\ in\ stock}{Total\ man\ hours\ spent\ in\ put\ away\ activity}\ products/man\_hour$$

5.2.3 Quality indicators

The dimension of quality is important in terms of accuracy and customer satisfaction. Besides that, we can use it to measure suppliers on their delivery performance. The interval in which we measure quality indicators is quarterly.

On-time performance (indicator 9)

This indicator measures the percentage of deliveries at the agreed delivery date. The time interval in which we measure is quarterly. With this indicator every individual supplier can be measured on their service rate. The frequency of checks is based on the quarterly service rate of the supplier. Thus, a supplier with a low service rate can be checked weekly or monthly, and a supplier with a high service rate can be checked quarterly.

$$On\_time\ performance = \frac{Number\ of\ deliveries\ received\ on\ time}{Total\ number\ of\ deliveries} * 100\%$$

Check accuracy (indicator 10)

This indicator measures the percentage of products that are checked correctly. Correct could be in the right amount or in the right time if there are appointments about the maximum handling time of checking products.

$$Check\ accuracy = \frac{Number\ of\ correctly\ checked\ products}{Total\ number\ of\ checked\ products} * 100\ \%$$

Put away accuracy (indicator 11)

This indicator measures the percentage of products that are stored in the correct storage location.

$$Put\ away\ accuracy = \frac{Number\ of\ products\ stored\ in\ correct\ location}{Total\ number\ of products\ that\ are\ put\ in\ stock} * 100\ \%$$

5.2.4 Utilization indicators

Utilization indicators are useful to indicate when more space or staff capacity is needed. The utilization indicators are just snapshots at a specific point in time and thus differ continuously.

Receive area utilization (indicator 12)

Ratio of occupied space in the receive area.

$$Receive\ area\ utilization = \frac{Space\ capacity\ used\ in\ the\ receive\ area}{Total\ space\ capacity\ in\ the\ receive\ area} * 100\ \%$$

Check area utilization (indicator 13)

Ratio of occupied space in the check area.

$$Check\ area\ utilization = \frac{Space\ capacity\ used\ in\ the\ check\ area}{Total\ space\ capacity\ in\ the\ check\ area} * 100\ \%$$

Interim storage utilization (indicator 14)

Ratio of occupied space in the interim storage zone.

$$Interim\ storage\ utilization = \frac{Space\ capacity\ used\ in\ the\ interim\ storage\ zone}{Total\ space\ capacity\ in\ the\ interim\ storage\ zone} * 100\ \%$$

This section gives fourteen different performance indicators to solve problem 1. We use the performance indicators in the experiment in practice that we describe in Section 5.3 and the dock to stock time indicator (performance indicator 1) in the simulation model in Section 5.4.

5.3 Experiment in practice

During the research project we test five interventions, related to problems 2 to 5: Staff capacity, available space, quality and checking, and from checked to stored. We use performance indicators (related to problem 1, see Section 5.2) to measure the effects of the interventions. The interventions together form the experiment.

5.3.1 Experimental set-up

Table 5.2 gives a timeline of the interventions. We explain the interventions briefly after the table. The interventions are numbered chronologically. The test period of intervention II is short because intervention IV is a follow-up of intervention II. The test period of intervention III is short because the intervention failed. When executing this intervention the number of output picks was 25% lower than the week before. We decide to skip this intervention due to the lack of time.

Month	March				April				May		
Week	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
First day of the week	**7**	**14**	**21**	**28**	**4**	**11**	**18**	**25**	**2**	**9**	**16**
Intervention I: Extra operator for unloading trucks											
Intervention II: Extra operator at put away activity											
Intervention III: Extra operator at distribution hall on Tuesday											
Intervention IV: Making all operators at the man-up forklifts responsible for put away operations											
Intervention V: Training of operators											

Action

Failed

Table 5.2 – Timeline of the interventions

<u>Intervention I - Extra operator for unloading trucks:</u>

Adding one extra operator from 7:30 AM to 4:00 PM for unloading of trucks (receive activity). This is based on the measurement that 95.2% of the deliveries arrive at the distribution centre before 4:00 PM. With this intervention, the other two skilled operators (instead of one operator) perform the check activity and are disturbed less frequently to unload trucks from 7:30 AM to 4:00 PM. Recall that there are constantly two persons to perform the check activity in shifts from 6:00 AM to 2:00 PM and from 2:00 PM to 10:00 PM.

Related problems: Staff capacity, available space, quality and checking, and from checked to stored.

<u>Intervention II - Extra operator at put away activity:</u>

Adding one extra operator from 7:30 AM to 4:00 PM for the put away activity of products that must be stored in the full pallet or box warehouse. This is based on measurements that the interim storage locations have high occupation rates (frequently with an overflow), and the fact that the put away time is too long (5:30:33 working hours in week 10 to week 13). With this intervention there are two persons instead of one directly involved with the put away activity from 7:30 AM to 4:00 PM.

Related problems: Staff capacity, available space, and from checked to stored.

Intervention III - Extra operator at distribution hall:

Adding one extra operator at the distribution hall on Tuesday. This is based on the measurement that Tuesday is a busy day with a lot of outbound picks whereby only 53.0% (in week 10 to week 14) of the inputs that are checked on Tuesday are confirmed on location on Tuesday.

Related problems: Staff capacity, available space, and from checked to stored.

Intervention IV - Making all operators at the man-up forklifts within the aisles of the full pallet and box warehouse responsible for put away operations:

Operators prefer to only execute pick operations and postpone put away operations until the evening. The result of the intervention is that operators switch more frequently between pick and put away operations. It is difficult to express the meaning of “more frequently” beforehand, but we expect that the intervention results in shorter put away times and thus shorter dock to stock times.

Related problems: Staff capacity, available space, and from checked to stored.

Intervention V - Training of operators:

Another intervention is training of operators. Operators must be more flexible in their working activities. Therefore the goal of this intervention is to train the check skills of other warehouse operators, to ensure that other warehouse operators can replace goods receipt operators. This is an ongoing intervention, since training the operators takes more time than the duration of the research project. Therefore this intervention has no direct influence on the measurements.

Related problems: Staff capacity and quality and checking.

5.3.2 Measurement

During the experiment we measure several indicators to give insight into the performance of the inbound process and the effects of the interventions. The time interval we choose to analyse the results is weekly. We choose this interval because the time interval of the current productivity is weekly, and we want to compare the results of the interventions with the results before the start of the experiment. Besides that, it is inefficient to analyse each day individually due to fluctuations. Therefore we take the average of the measurements over the week. We describe the different performance indicators per dimension.

Time indicators

The dock to stock time, receive time, and check time (performance indicators 1 to 3) cannot be calculated from the data of the ERP-system. The only reliable time indicator that we can calculate from the data of the ERP-system is the put away time (performance indicator 4).

Productivity indicators

The productivity indicator that we use is the currently used productivity indicator. We use this indicator to compare the outcomes of the interventions with the outcomes before the start of the experiment. With the comparison we check the influence of the interventions on the productivity indicator. We do not use performance indicators 5 to 8 because the ERP-system requires modification to calculate these indicators. This is not possible in the short time period.

Quality indicators

We do not use the quality indicators (performance indicators 9 to 11) because we are not interested in the influence of the interventions on the quality indicators during the experiment in practice.

Utilization indicators

Since the interventions are focused on the internal process, the utilization indicators are useful to indicate the influence of an intervention on the utilization at the different areas. We decide to use the utilization indicators 12 to 14: Receive area utilization, check area utilization, and interim storage utilization.

We choose to measure the utilization indicators at two specific points in time, namely 8:00 AM and 2:00 PM. Recall that the duration of the first shift is from 6:00 AM to 2:00 PM and the duration of the second shift from 2:00 PM to 10:00 PM. We choose to measure at 8:00 AM instead of 6:00 AM for the simple reason that the working day at the office starts at 8:00 AM, and 8:00 AM is the first opportunity for the researcher to measure. We measure at the beginning of both shifts because it gives insight into the progress over a shift. Besides that, it is important to use two fixed measurements in order to compare the outcomes. Appendix B provides all the measurements from week 10 to week 20. Notice that it is just a snapshot at a specific point in time, but it gives at least some indication of the results of the interventions.

Receive area utilization (performance indicator 12):

This is the ratio of occupied space under the shelter roof. When the utilization is 100% and new products arrive, products must be stored either outside for a while or on a staging area in the distribution hall. This is called overflow in the measurements. When products are stored on staging areas, the indicator number of staging areas used shows this (indicator 15).

Check area utilization (performance indicator 13):

This measure is used to check the storage utilization at the check area. When the check area is 100% it could be that already checked products cannot be sent to the interim storage location (see performance indicator 14) because this place is completely occupied.

Interim storage utilization (performance indicator 14):

This measure is used to check the storage utilization at the interim storage location. When the utilization is 100% and there arrive new products, they must be stored outside the allocated space. This is called overflow in the measurements. Sometimes already checked products are stored on staging areas.

Additional indicators

Because there are more factors that influence the performance of the inbound process we decide to add four measurements that are specific for the inbound process at the distribution centre of Wavin. We measure these indicators also at 8:00 AM and 2:00 PM.

Number of used staging areas (indicator 15):
This indicator gives the number of staging areas that is used for the inbound process. When the utilization of the receive area is high, staging areas are used to store products. Sometimes it is also used when the utilization of the interim storage location or the number of pick & drop points is high.

Number of working days ago that the current batch at the check activity is unloaded (indicator 16):
This indicator measures the progress at the check activity. When the current booking day of the batch at the check activity is equal to the day of unloading, the number is 0. When the current batch is unloaded the previous working day the number is 1, et cetera.

Number of used drop points (indicator 17):
This indicator measures the number of used drop points at the front-ends of the aisles. In the full pallet warehouse there are 4 drop points per aisle (4 aisles) and in the box warehouse there are 3 drop points per aisle (10 aisles). So there are maximal 4x4+3x10 = 46 drop points available. When the number of used drop points is below 10 and the interim storage utilization is above 50% there are problems with moving products from the interim storage location to the drop points. When the number of used drop points is above 32, it could be that the number of occupied man-up forklifts (indicator 18) is insufficient.

Number of occupied man-up forklifts (indicator 18)
The fourth one is the number of occupied man-up forklifts. This measure shows the number of occupied man-up forklifts within the aisles of the full pallet and box warehouse. Most of the time there is 1 man-up forklift within the aisles of the full pallet warehouse and the number of man-up forklifts within the aisles of the box warehouse differs. The maximum number of forklifts is 6.

5.3.3 Results of the experiment
This section describes the results of the different interventions. Recall that we take the average of the measurements over a week. We choose a weekly time interval because the time of the current productivity indicator is weekly, and we want to compare the results of the interventions with the results before the start of the experiment. Besides that, it is inefficient to analyse each day individually due to fluctuations. Therefore we take the average of the measurements over the week. Appendix B provides the measurements from week 10 to week 20 that we perform daily at 8:00 AM and 2:00 PM, namely utilization indicators 12 to 14 and additional indicators 15 to 18.

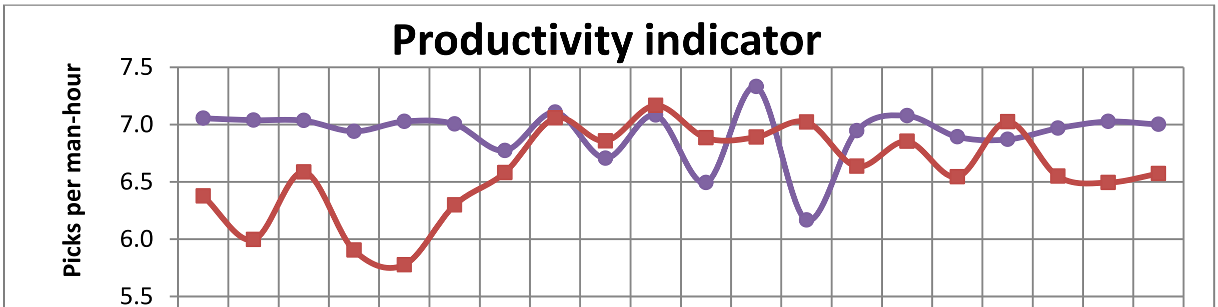
<u>Intervention I: Extra operator for unloading trucks</u>
Based on the measurement that 95.2% of the deliveries arrive at the distribution centre before 4:00 PM we decide to add one extra operator from 7:30 AM to 4:00 PM for unloading of trucks (receive activity). At the start of this experiment (week 10 2016) the following things are noticed:

- The receive area utilization is frequently 100% and results in an overflow. The receive area utilization is on average 74%.
- 1 or 2 staging areas are frequently occupied with unloaded products that must be checked.
- The number of days ago that the batch at the check activity is unloaded, is 2 or even 3 days.
- The interim storage utilization is frequently 100% and there is an overflow.

In week 14 we analyse the performance of the inbound process from week 10 to week 13:

- The average utilization at the receive area reduced from 74% to 54% and staging areas in week 11 to week 13 are not used for storing unloaded products anymore.
- The number of days ago that the current batch at the check activity is unloaded, is reduced from 2 to 1 working day. Sometimes at the measurement of 2:00 PM, the operators at the check activity are working on a batch that is unloaded at the distribution centre the same day.
- 1 staging area is occupied with already checked products, during a measurement in week 12. The reason is that the average check time is shorter and therefore the interim storage is more frequently occupied.
- Because more products are checked per hour, the interim storage location is frequently fully occupied and this results in an overflow.
- The average put away time in week 10 to week 13 is 5:30:33 working hours.

When analysing the productivity indicator, we encounter some fluctuations since the start of the experiment in week 10 (see Figure 5.3). The productivity in week 12 reached a level of 7.33 picks per man-hour. This is not reached since week 45 in 2013. The low productivity rate of 6.17 in week 13 is the result of a breakdown of the ERP-system. From the beginning of week 14 the productivity indicator returns to stable rates of around 7 picks per man-hour. Overall, the average productivity in the first 20 weeks increased from 6.60 in 2015 to 6.93 in 2016. This is an increase of 5.0% compared to the same period in 2015.



Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2016	7.1	7.0	7.0	6.9	7.0	7.0	6.8	7.1	6.7	7.1	6.5	7.3	6.2	6.9	7.1	6.9	6.9	7.0	7.0	7.0
2015	6.4	6.0	6.6	5.9	5.8	6.3	6.6	7.1	6.9	7.2	6.9	6.9	7.0	6.6	6.9	6.5	7.0	6.5	6.5	6.6

Figure 5.3 - Productivity performance indicator

The importance of two operators that are responsible for the check activity is noticed during week 17. A combination of more incoming products and understaffing at the check activity, results again in occupied staging areas. Also the number of days ago that the current batch at the check activity is unloaded, falls back to 3 days. Due to several non-working days this continues until week 19, see Appendix B. This emphasizes the importance of constantly having two operators at the check activity.

<u>Intervention II: Extra operator at put away activity</u>

Because of the extra operator at the receive activity, more products are checked per hour. This results in even higher occupation rates at the interim storage locations. Therefore extra capacity is needed at the put away activity. We choose to add one operator that is responsible to move the pallets from the interim storage location to the drop points at the front end of the right aisle.

The occupation at the interim storage location logically drops down (from 64% in week 10 to week 13, to 49% in week 14 to week 15) and also the put away times decreased from 5:30:33 working hours in week 10 to week 13, to 4:36:17 working hours in week 14 to week 15. This is a reduction of 0:54:16 working hours compared to week 10 to week 13.

Intervention III: Extra operator on Tuesday

Tuesday is usually a busy day for the warehouse team with a lot of output picks. Therefore, the put away time is longer on Tuesday and many products that are checked on Tuesday are confirmed on location on Wednesday. This is also encountered with the measurements. The interim storage utilization indicator is frequently 100% (also with an overflow) on Tuesday and Wednesday because the warehouse operators are busy with outbound deliveries. When executing the experiment the number of output picks in the warehouse was 25% lower than the week before. Therefore, the operator was sent to the piece pick warehouse to execute other activities and the experiment failed. We decide to skip this experiment due to the lack of time and go one with intervention IV and V.

Intervention IV: Making all operators at the man-up forklifts responsible for put away operations

From the beginning of week 16 we test that operators within the aisles of the full pallet and box warehouse switch more frequently between pick and put away operations. This results in shorter waiting times at the put away activity. The productivity performance indicators stays stable (see Figure 5.3) and the ratio of ratio of occupied space decreased from 49% in week 14 to week 15, to 35% in week 16 to week 20. Note that cranes stay in the same aisle for a long time to pick the products they need. This can result in full pick/drop points at unoccupied aisles, and empty pick/drop points at occupied aisles. The put away time reduced from 4:36:17 working hours in week 14 to week 15, to 3:24:49 working hours in week 16 to week 19. This is a reduction of 1:11:28 working hours compared to week 14 to week 15.

Intervention V: Training of operators

Several warehouse operators are trained in doing the check activity. Therefore other operators can replace the current operators in case of illness/holidays. Operators can also help during peak hours or with overwork on Saturday. As already mentioned, this is an ongoing intervention, since training operators takes more time than the duration of the research project. Therefore this intervention has no direct influence on the measurements and it is hard to derive quantitative results from the data.

Table 5.3 shows the most important outcomes of the experiment in practice. Performance indicator 4 is derived from the ERP-system and performance indicators 12 to 14 are based on the measurements in Appendix B.

Week	Put away time (performance indicator 4)	Week	Receive area utilization (performance indicator 12)	Check area utilization (performance indicator 13)	Interim storage utilization (performance indicator 14)
10-13	5:30:33 working hours	**10-13**	54%	68%	64%
14-15	4:36:17 working hours	**14-15**	43%	51%	49%
16-19	3:24:49 working hours	**16-20**	48%	44%	35%

Table 5.3 - Results of the experiment in practice

With the use of different interventions we tried to solve problems 2 to 5: Staff capacity, available space, quality and checking, and from checked to stored. Besides that, we test several performance indicators to measure the results of the different interventions. We describe the recommended improvements in Section 5.5. Another factor that influences the performance of the inbound process is the planning of incoming deliveries. Scheduled deliveries are useful to plan the staff capacity and create an even workflow. We try to find improvements about problem 6: Planning of deliveries, through the use of a simulation model in Section 5.4.

5.4 Simulation model

Besides the interventions that we test in practice, we also want to test the influence of planning deliveries to create an even workflow (problem 6). Because it is hard to test different interventions in practice, we choose to build a simulation model. The interventions that we test are complex to experiment in practice because Wavin has a lot of different suppliers. The interventions require new agreements with (all) suppliers and this is not possible within the short time period. Besides that, we first want to know the outcomes of a certain intervention before we recommend the intervention in practice.

The simulation model that we use in this section is a dynamic, stochastic, and discrete event simulation. Appendix C provides more information about the simulation model and the different choices we make. This section describes the most important results of the simulation model.

<u>Objective of the simulation model</u>

We provide the stakeholders of the project with possible improvements about scheduled deliveries. We use the simulation model to experiment with settings that are hard to test in reality in the short time period.

<u>Scope and level of detail:</u>

We simulate the general inbound process (receive, check, and put away activity) at the distribution centre of Wavin for products from own factories, internal suppliers, and external suppliers. Products are stored in one of the four different storage locations (<u>inside</u> the building): automatic pallet warehouse, full pallet warehouse, box warehouse, or piece pick warehouse. The number of products and their storage destination are substituted from historical data of 65 working days, from 31 August 2015 to 29 November 2015. Products from the packaging line and returns are excluded. Appendix C provides the data that we use to model the receive, check, and put away activity.

<u>Inputs:</u>

The inputs of the model can be used as experimental factors.

- Number of incoming products per supplier on daily basis.
- Arrival time of suppliers.
- Storage locations.
- Check, receive, and put away times.

Outputs:

We use the outputs of the model to measure the performance of the model when experimenting with the different experimental factors.

- Average dock to stock time (performance indicator 1) and the percentage that is handled within 24 hours.
- Number of products that are handled within a certain period.

Figure 5.4 shows the flowchart of the simulation model. The division of arrivals from internal and external suppliers over the days in a week are based on historical data. Products from own production do not have waiting time at the receive station since they are moved directly to the check area when they arrive at the distribution centre.

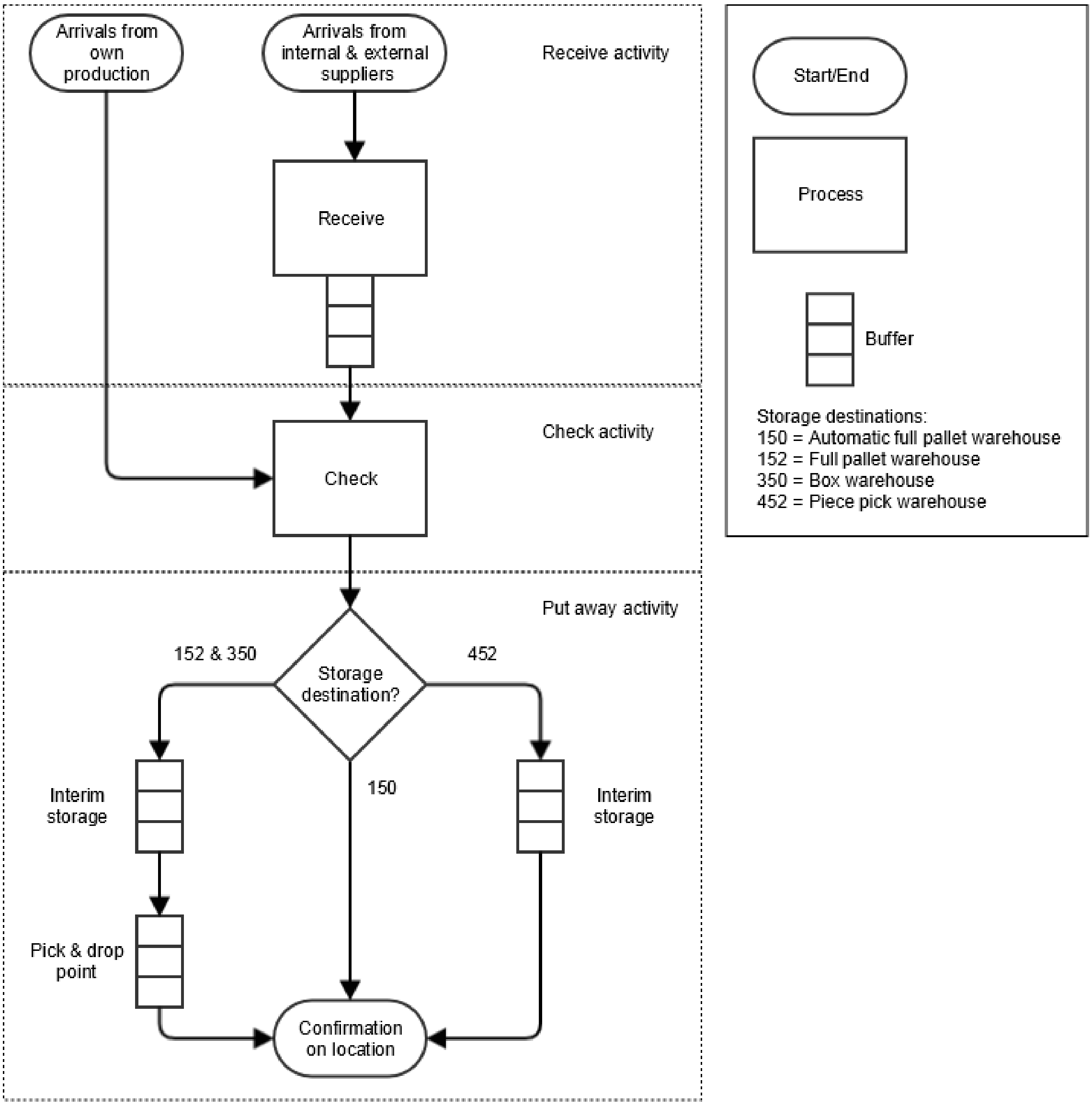


Figure 5.4 - Flowchart of the simulation model

Number of replications and run length

The number of independent replications (for the worst case) in the simulation model is 16 and the run length is 65 days, which is the same length as the historical input data. Appendix C provides more details about the calculation of the number of replications.

Specific questions:

1) What is the impact on the dock to stock time if deliveries from Poland deliver products exactly on 08:00 AM?
2) What happens if deliveries from Poland always arrive between 6 AM and 10 AM?
3) What happens when the deliveries are equally divided over the day from 6 AM to 10 PM?
4) What is the impact on the dock to stock time when the number of incoming products is equally divided over the week?
5) What is the impact on the dock to stock time when the number of incoming products is equally divided over the week and over the day?
6) What happens when the total number of incoming products is 1.5 or even 2 times higher?

Recall that question 5 is a combination of questions 3 and 4.

Limitations

Due to the absence of data, we make many assumptions in the simulation model. Although we verify the inputs of the simulation model with subject matter experts, we notice that the average dock to stock time of the basic simulation model is shorter than the (expected) average dock to stock time in reality. The check times that we use in the simulation model (based on data from the ERP-system) are shorter than the check times in reality and this results in lower dock to stock times. It is hard to approximate a distribution function in accordance with subject matter experts because the check time differs a lot per supplier. Therefore we use the historical data from the ERP-system to model the check times. The consequence is that the savings of the different interventions within the simulation model are less than in reality. The expectation is that the savings in reality are even more significant.

5.4.1 Results of the simulation

This section provides short answers on the formulated questions. The total number of input records is 12,190. The output of the basic model results in an average dock to stock time of 14:25:49 hours derived from 12,172 records. 81.9% of the products is confirmed on location within 24 hours.

1) What is the impact on the dock to stock time if deliveries from Poland deliver products exactly on 08:00 AM?

Almost a quarter of the records are deliveries from Poland. When these deliveries arrive exactly on 08:00 AM, the inbound process can be customized to handle these daily deliveries. The result of this intervention is that the average dock to stock time reduces to 13:58:58 hours derived from 12,179 records. A reduction of 0:26:51 hours compared to the basic model. 82.4% of the products is confirmed on location within 24 hours.

2) What happens if deliveries from Poland always arrive between 6 AM and 10 AM?

For truck drivers from Poland it is hard to arrive exactly on 8 AM due to traffic jam or other circumstances. Therefore, we test the impact on the dock to stock time when the deliveries from Poland always arrive between 6 AM and 10 AM. The result of this intervention is that the average dock to stock time reduces to 13:50:59 hours derived from 12,178 records. A reduction of 0:34:50 hours compared to the basic model. 82.9% of the products is confirmed on location within 24 hours.

Table 5.4 shows the empirical distributions arrival times that we use for each question, compared to the basic simulation model. Recall that the only thing we change in questions 1 and 2 is the arrival from Poland, and the arrivals of questions 3 to 6 apply to all internal and external suppliers.

Time	Basic model	Question 1	Question 2	Question 3	Question 4	Question 5	Question 6
Applies to	Internal and external suppliers	Poland	Poland	Internal and external suppliers	Internal and external suppliers	Internal and external suppliers	Internal and external suppliers
6:00 AM - 7:00 AM	3.57%	0.00%	25.00%	6.25%	3.57%	6.25%	3.57%
7:00 AM - 8:00 AM	7.14%	100.00% on 8:00 AM	25.00%	6.25%	7.14%	6.25%	7.14%
8:00 AM - 9:00 AM	9.52%	0.00%	25.00%	6.25%	9.52%	6.25%	9.52%
9:00 AM - 10:00 AM	19.05%	0.00%	25.00%	6.25%	19.05%	6.25%	19.05%
10:00 AM - 11:00 AM	14.29%	0.00%	0.00%	6.25%	14.29%	6.25%	14.29%
11:00 AM - noon	16.67%	0.00%	0.00%	6.25%	16.67%	6.25%	16.67%
noon - 1:00 PM	9.52%	0.00%	0.00%	6.25%	9.52%	6.25%	9.52%
1:00 PM - 2:00 PM	5.95%	0.00%	0.00%	6.25%	5.95%	6.25%	5.95%
2:00 PM - 3:00 PM	8.33%	0.00%	0.00%	6.25%	8.33%	6.25%	8.33%
3:00 PM - 4:00 PM	1.19%	0.00%	0.00%	6.25%	1.19%	6.25%	1.19%
4:00 PM - 5:00 PM	1.19%	0.00%	0.00%	6.25%	1.19%	6.25%	1.19%
5:00 PM - 6:00 PM	2.38%	0.00%	0.00%	6.25%	2.38%	6.25%	2.38%
6:00 PM - 7:00 PM	1.19%	0.00%	0.00%	6.25%	1.19%	6.25%	1.19%
7:00 PM - 8:00 PM	0.00%	0.00%	0.00%	6.25%	0.00%	6.25%	0.00%
8:00 PM - 9:00 PM	0.00%	0.00%	0.00%	6.25%	0.00%	6.25%	0.00%
9:00 PM - 10:00 PM	0.00%	0.00%	0.00%	6.25%	0.00%	6.25%	0.00%
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 5.4 - Overview of the input distribution

3) What happens when all deliveries are equally divided over the day from 6 AM to 10 PM?

With this intervention we test the influence of an equally division of arrivals over the day. So the deliveries from internal and external suppliers are spread equally over the day (see Table 5.4). Recall that the total number of incoming records per day is not equally divided with this intervention. The result of this intervention is that the average dock to stock time reduces to 13:28:30 hours derived from 12,153 records. A reduction of 0:57:19 hours compared to the basic model. 87.7% of the products is confirmed on location within 24 hours.

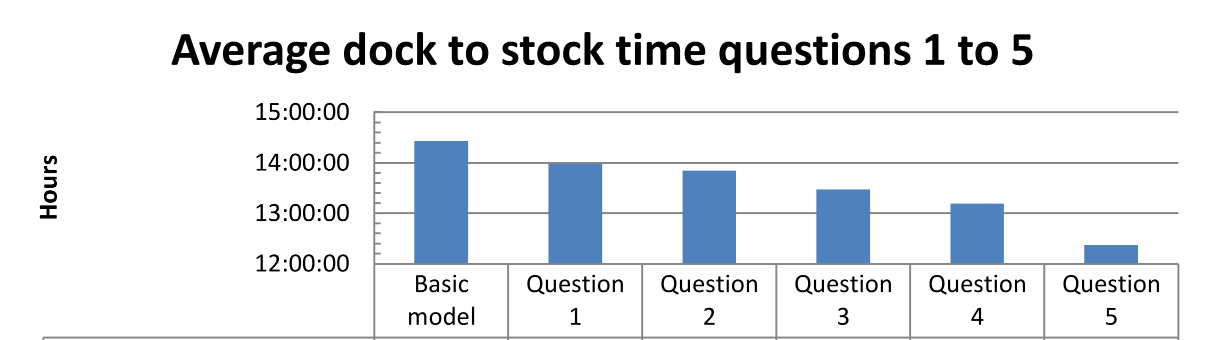
4) What is the impact on the dock to stock time when the number of incoming products is equally divided over the week?

With this intervention we test what the effect is when the total number of incoming products is the same for each day. Recall that the arrival times of trucks are the same as the basic model. The average dock to stock time reduces to 13:11:44 hours derived from 12,135 records, a reduction of 1:14:05 hours. 87.8% of the products is confirmed on location within 24 hours.

5) What is the impact on the dock to stock time when the number of incoming products is equally divided over the week and over the day?

With this intervention we combine questions 3 and 4. We test what the effect is when the total number of incoming products is the same for each day, and when the deliveries from internal and external suppliers are spread equally over the day. The result of this intervention is that the average dock to stock time reduces to 12:22:26 hours derived from 12,137 records, a reduction of 2:03:23 hours compared to the basic model. 91.8% of the products is confirmed on location within 24 hours.

Figure 5.5 shows the results of the first five questions.



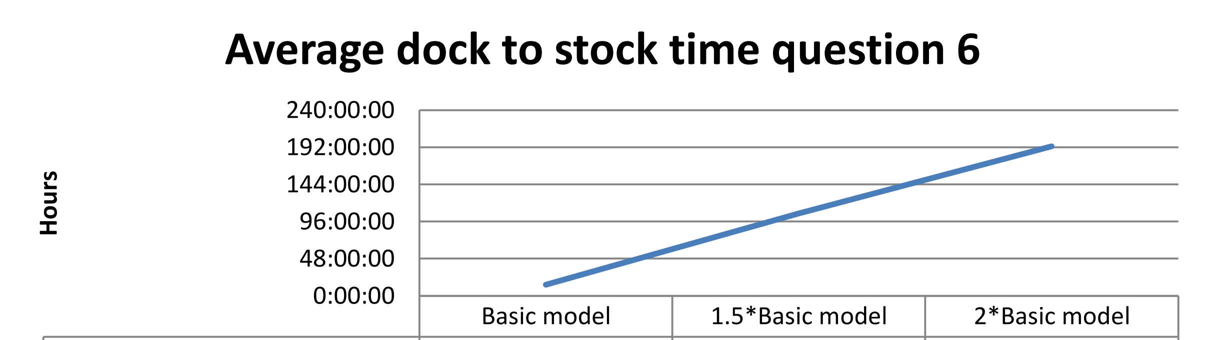
	Basic model	Question 1	Question 2	Question 3	Question 4	Question 5
Average dock to stock time	14:25:49	13:58:58	13:50:59	13:28:30	13:11:44	12:22:26

Figure 5.5 - Overview of the average dock to stock times of questions I to V

6) What happens when the total number of incoming products is 1.5 or even 2 times higher?

We also want to test some extreme values to check if the system remains stable. When the total number of incoming products is 1.5 times higher (18,285 instead of 12,190 records) the average dock to stock time increases to 106:17:01 hours derived from 15,968 records. 43.4% of the products is confirmed on location within 24 hours. An increasing of 91:51:12 hours compared to the basic model.

When the total number of incoming products is 2 times higher (24,380 instead of 12,190 records), the average dock to stock time increases to 193:10:39 hours derived from 16,538 records. 40.4% of the products is confirmed on location within 24 hours. An increasing of 178:44:50 hours compared to the basic model. Since the average dock to stock time is more than 8 days the system does not remain stable. This means that the system explodes and this results in long queues (see Figure 5.6). Thus, when the number of incoming product grows in the future, the inbound process needs to be redesigned. This is an opportunity for further research.



	Basic model	1.5*Basic model	2*Basic model
Average dock to stock times	14:25:49	106:17:01	193:10:39

Figure 5.6 – Overview of the average dock to stock times of question IV

5.5 Solving the problems

This section provides information about how to solve the indicated problems.

Problem 1 – Performance monitoring:

Section 5.2 describes different indicators to measure the performance of the inbound process. We use some of the performance indicators in the experiment in practice and the simulation model. Because not all performance indicators can be obtained from the ERP-system there is need to modify the ERP-system. Implementation of new performance indicators lead to extra time spent, but the lost time can be gained back later in the process. However, we recommend to use the following performance indicators:

Time indicators

Dock to stock time (performance indicator 1)	
Definition	Lead time from product arrival until the product is available for picking
Formula	$$Average\ dock\ to\ stock\ time = \frac{\sum_{i=1}^{N} Dock\ to\ stock\ time\ (i)}{N}\ hours$$ $$Dock\ to\ stock\ time\ (i) = Confirmation\ time\ on\ location\ (i) - Arrival\ time\ (i)$$ $$Product\ i = 1,2,3, \ldots, N$$
Purpose	Indicate the average lead time and how quickly products can be ordered by customers
Data source	ERP-system
Time interval	Weekly

Receive time (performance indicator 2)	
Definition	Lead time from product arrival to the beginning of the check activity
Formula	$$Average\ receive\ time = \frac{\sum_{i=1}^{N} Receive\ time\ (i)}{N}\ hours$$ $$Receive\ time\ (i) = Begin\ of\ check\ time\ (i) - Arrival\ time\ (i)$$ $$Product\ i = 1,2,3, \ldots, N$$
Purpose	Indicate the average receive time plus the waiting time before the products are checked
Data source	ERP-system
Time interval	Weekly

Check time (performance indicator 3)	
Definition	Lead time to check a product
Formula	$$Average\ check\ time = \frac{\sum_{i=1}^{N} Check\ time\ (i)}{N}\ hours$$ $$Check\ time\ (i) = End\ of\ check\ time\ (i) - Begin\ of\ check\ time\ (i)$$ $$Product\ i = 1,2,3, \ldots, N$$
Purpose	Indicates when there are problems with the check activity and to test individual suppliers on their performance
Data source	ERP-system
Time interval	Weekly

Put away time (performance indicator 4)	
Definition	Lead time from the moment that a product is checked to when it is stored in its destined location
Formula	$$Average\ put\ away\ time = \frac{\sum_{i=1}^{N} Put\ away\ time\ (i)}{N}\ hours$$ $$Put\ away\ time\ (i) = Confirmation\ time\ on\ location\ (i) - End\ of\ check\ time\ (i)$$ $$Product\ i = 1,2,3, \ldots., N$$
Purpose	Minimize the waiting times before products are confirmed on location
Data source	ERP-system
Time interval	Weekly

Productivity indicators

Receive productivity (performance indicator 5)	
Definition	Number of products unloaded per man-hour
Formula	$$Receive\ productivity = \frac{Total\ number\ of\ unloaded\ products}{Total\ man\ hours\ spent\ in\ the\ receive\ activity}\ products/man\_hour$$
Purpose	Check if there are problems with unloading
Data source	ERP-system
Time interval	Weekly

Check productivity (performance indicator 6)	
Definition	Number of products checked per man-hour
Formula	$$Check\ productivity = \frac{Total\ number\ of\ checked\ products}{Total\ man\ hours\ spent\ in\ the\ check\ activity}\ products/man\_hour$$
Purpose	To monitor the productivity of the check activity
Data source	ERP-system
Time interval	Weekly

Check returns productivity (performance indicator 7)	
Definition	Number of products checked per man-hour
Formula	$$Check\ returns\ productivity = \frac{Total\ number\ of\ returns\ that\ are\ checked}{Total\ man\ hours\ spent\ for\ checking\ returns}\ returns/man\_hour$$
Purpose	To monitor the productivity of the check activity of returns
Data source	ERP-system
Time interval	Weekly

Put Away productivity (performance indicator 8)	
Definition	Number of products checked per man-hour
Formula	$Put\ away\ productivity = \frac{Total\ number\ of\ products\ that\ are\ put\ in\ stock}{Total\ man\ hours\ spent\ in\ put\ away\ activity}\ products/man\_hour$
Purpose	Gives insight into the productivity of the operators at the put away activity
Data source	ERP-system
Time interval	Weekly

Quality indicators

On-time performance (performance indicator 9)	
Definition	Ratio of deliveries that arrive on the agreed delivery date
Formula	$On\_time\ performance = \frac{Number\ of\ deliveries\ received\ on\ time}{Total\ number\ of\ deliveries} * 100\%$
Purpose	Gives into the performance of suppliers
Data source	ERP-system
Time interval	Quarterly, when preferred weekly for individual suppliers

Check accuracy (performance indicator 10)	
Definition	Ratio of products checked correctly
Formula	$Check\ accuracy = \frac{Number\ of\ correctly\ checked\ products}{Total\ number\ of\ checked\ products} * 100\ \%$
Purpose	This indicator measures the percentage of products that are checked correctly
Data source	ERP-system
Time interval	Quarterly, when preferred weekly for individual suppliers

Put Away accuracy (performance indicator 11)	
Definition	Ratio of products stored in correct location
Formula	$Put\ away\ accuracy = \frac{Number\ of\ products\ stored\ in\ correct\ location}{Total\ number\ of products\ that\ are\ put\ in\ stock} * 100\ \%$
Purpose	Measures the percentage of products that are stored in the correct location
Data source	ERP-system
Time interval	Quarterly, when preferred weekly

Utilization indicators

Receive area utilization (performance indicator 12)	
Definition	Ratio of occupied space in the receive area
Formula	$Receive\ area\ utilization = \frac{Space\ capacity\ used\ in\ the\ receive\ area}{Total\ space\ capacity\ in\ the\ receive\ area} * 100\ \%$
Purpose	Moment observation when problems arise
Data source	Manual measurement
Time interval	Only in case of problems

Check area utilization (performance indicator 13)	
Definition	Ratio of occupied space in the check area
Formula	$Check\ area\ utilization = \frac{Space\ capacity\ used\ in\ the\ check\ area}{Total\ space\ capacity\ in\ the\ check\ area} * 100\ \%$
Purpose	Moment observation when problems arise
Data source	Manual measurement
Time interval	Only in case of problems

Interim storage utilization (performance indicator 14)	
Definition	Ratio of occupied space in the interim storage zone
Formula	$Interim\ storage\ utilization = \frac{Space\ capacity\ used\ in\ the\ interim\ storage\ zone}{Total\ space\ capacity\ in\ the\ interim\ storage\ zone} * 100\ \%$
Purpose	Moment observation when problems arise
Data source	Manual measurement
Time interval	Only in case of problems

Problem 2 - Staff capacity:

Section 5.3 describes different interventions that are related to staff capacity. Based on the experiment in practice, we recommend the following:

Add one operator at the receive activity from 7:30 AM to 4:00 PM for unloading of trucks (intervention I). This is based on the measurement that 95.2% of the deliveries arrive at the distribution centre before 4:00 PM. With this intervention, the other two skilled operators (instead of one operator) can do the check activity and are disturbed less frequently to unload trucks. The first task of the extra operator is to unload trucks. If there are no trucks that must be unloaded, the operator moves the products from the receive area to the check area, and already checked products from the check area to the interim storage location.

Furthermore, we have introduced that operators at the man-up forklifts must switch more frequently between pick and put away operations within the full pallet and box warehouse (intervention IV). Most of the time 4 cranes are occupied, 1 within the full pallet warehouse and 3 within the box warehouse. Thus 3 out of 10 aisles are continuously occupied in the box warehouse. The result is that the interim storage location is used less frequently. Intervention IV starts in week 16. The put away time (performance indicator 4) reduced from 5:30:33 working hours in week 10 to week 13, to 3:24:49 working hours in week 16 to week 19, a reduction of 2:05:44 working hours.

Another intervention that is related to the staff capacity is the training of operators (intervention V). The check skills of several warehouse operators are improved during the project to ensure that they can replace the current goods receipt operators. This is an ongoing intervention, since training operators takes more time than the duration of the research project. The result of this intervention is that warehouse operators are more flexible to help during peak hours.

Problem 3 - Available space:
When the incoming deliveries are equally divided, operators within the aisles of the storage locations put away pallets more frequently, and there is one extra operator for unloading trucks, the current space is sufficient. This results in less intertwined traffic between inbound and outbound deliveries. Staging areas are not occupied by incoming deliveries anymore. The average space used on interim storage locations decreased from 64% to 35% during the interventions. Moreover, it is important to bring structure in the check area through the use of e.g. lines and signals.

The importance of providing an even workflow and constantly having two operators at the check activity is experienced during the experiment in practice. The number of full truck loads from Buk Poland per day was two instead of one for a certain week. One full truck load contains most of the time about 60 pallets, which requires a lot of space. The higher number of incoming pallets in relation with understaffing at the check activity results again in space issues. To solve this problem, we recommend to unload the earliest arriving truck from Poland at the distribution hall instead of storing it under the shelter roof. This (interim) storage place is also the check place of the pallets. This results in three movement-steps instead of five (see Figure 5.7 and Figure 5.8). Because the deliveries from Buk Poland are an outsourced form of own production, these deliveries have priority to other deliveries and thus do not have to follow the FIFO-rule.

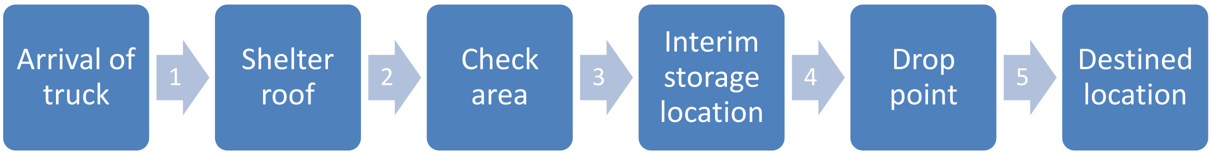


Figure 5.7 - Current situation of pallet movement to full pallet and box warehouse

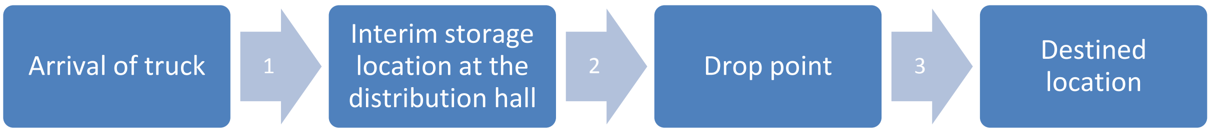


Figure 5.8 - Preferred situation of pallet movement to full pallet and box warehouse

Problem 4 - Quality and checking:
Since the staff capacity is rescheduled, the good receipt staff is more accurate to check deliveries because they are disturbed less frequently. Besides that, operators need to follow a structured approach. Pallets are spread within the check area and operators do not follow the sequence in which they are stored. This results in much walking time by searching for products. Figure 5.9 gives an overview of the current and the preferred situation, which results in time savings.

During the research project, Wavin imposed new delivery standards. The delivery standards are sent to all external suppliers. This should result in more correct deliveries that are essential to process the products quickly and accurately. Furthermore, Wavin can contact suppliers when they structurally deliver badly because suppliers sign they agree with the delivery standards. The delivery standards result also in time savings since less time is used for searching products.

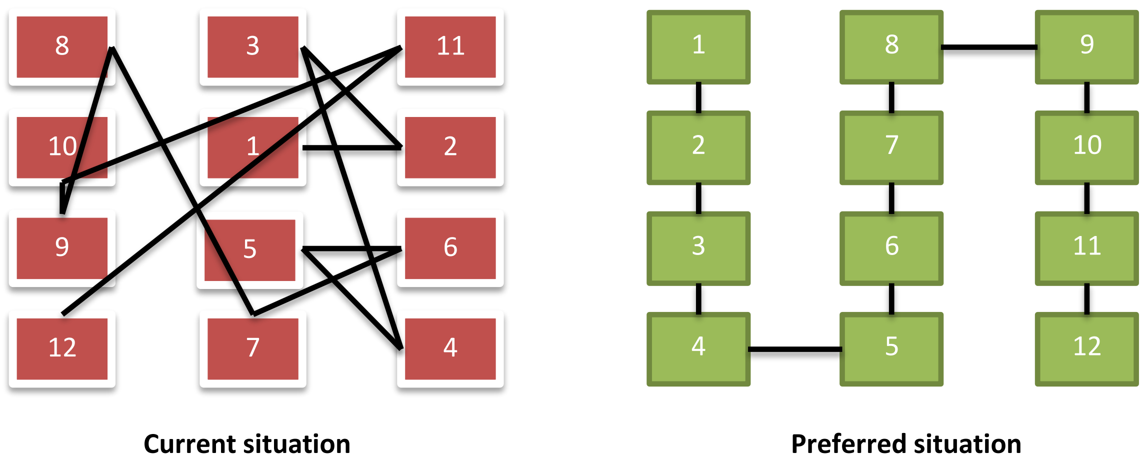


Figure 5.9 - Sequence of working

Problem 5 - From checked to stored:

The waiting time from checked to stored is reduced a lot since the products do not stay at the interim storage locations for a long time anymore. As already mentioned, the put away time reduced from 5:30:33 working hours in week 10 to week 13, to 4:36:17 working hours in week 14 to week 15, to 3:24:49 working hours in week 16 to week 19 when operators at the man-up forklifts switch more frequently between pick and put away operations within the aisles of the full pallet and box warehouse. Meetings with the warehouse team are very important to emphasize the importance of putting away pallets more frequently. The expectation is that the put away times reduce even more when the warehouse operators are aware of the importance to put away the pallets as soon as possible.

Problem 6 - Planning of incoming deliveries:

We have had conversations with different experts about the planning of incoming deliveries. At least for the deliveries from the production plant in Poland, there is some information available in the ERP-system about deliveries that come to the distribution centre in Hardenberg. When trucks are loaded in Poland, this information is available in the ERP-system. During the project this information is measured. The route duration from the plant in Poland to the distribution centre in Hardenberg is about 8 hours without stops or traffic jam. The transport is outsourced to a third-party logistics provider. Most of the time, the truck arrives the next working day in Hardenberg.

However, the simulation model in Section 5.4 shows that planning deliveries more efficiently results reduction of the dock to stock time. When the number of incoming products is equally divided over the week and over the day, the result is a reduction of 2:03:23 hours compared to the basic model (from 14:25:49 hours to 12:22:26 hours). 91.8% of the products is confirmed on location within 24 hours.

As already mentioned, during the project Wavin imposed new delivery standards. On this delivery standard it is noted that at least 95% of the orders must arrive on the agreed delivery date. Since suppliers have to sign for this delivery standard, Wavin can use this when suppliers structurally do not deliver their products on the agreed delivery date.

5.6 Conclusion

This section provides short answers on the formulated research questions.

4. <u>What can be done to improve the performance of the inbound process?</u>

Based on the outcomes of an experiment in practice and a simulation model, we provide several solutions that help to improve the performance of the inbound process:

- Add one extra operator for unloading trucks (receive activity).
- Make all operators at the man-up forklifts responsible for the put away activity.
- Train operators. Operators must be more flexible in their working activities.
- Use more performance indicators to continuously monitor the process, and act upon these indicators when problems arise.
- Reschedule the division of incoming deliveries over the week.

During the research project, the productivity indicator increased from 6.59 in 2015 to 6.96 in 2016. This is an increase of 5.6% compared to the same period in 2015 (week 1 to week 24). After making all operators at the man-up forklifts responsible for the put away activity, the put away time reduced from 5:30:33 working hours in week 10 to week 13 to 3:24:49 working hours in week 16 to week 19. This is a reduction of 2:05:44 working hours.

With the use of a simulation model we show that when the number of incoming products is equally divided over the week and over the day, the result is a reduction of 2:03:23 hours in the dock to stock time compared to the basic model (from 14:25:49 hours to 12:22:26 hours).

4.1. <u>Which indicators can be used to measure the performance of the inbound process?</u>

Table 5.5 shows the performance indicators to measure the performance of the inbound process.

Time indicators	Productivity indicators	Quality indicators	Utilization indicators
Dock to stock time	Receive productivity	On-time performance	Receive area utilization
Receive time	Check productivity	Check accuracy	Check area utilization
Check time	Check returns productivity	Put Away accuracy	Interim storage utilization
Put away time	Put Away productivity		

Table 5.5 – Overview of the performance indicators

4.2. <u>What can be done to solve the indicated problems?</u>

Problem 1 – Performance monitoring:

Use of performance indicators (see Table 5.5).

Problem 2 - Staff capacity:

Add one extra operator for unloading trucks. If there are no trucks that must be unloaded, the operator moves the products from the receive area to the check area, and already checked products from the check area to the interim storage location.

Problem 3 - Available space:
When the incoming deliveries are equally divided, operators within the aisles of the storage locations put away pallets more frequently, and there is one extra operator for unloading trucks, the current space is sufficient.

Problem 4 - Quality and checking:
Since the staff capacity is rescheduled, the good receipt staff is more accurate to check deliveries because they are disturbed less frequently. Besides that, operators need to follow a structured approach. During the research project, new delivery standards are imposed by Wavin. Correct deliveries result in shorter processing times at the check activity. The above mentioned performance indicators can be used to measure the performance of different suppliers.

Problem 5 - From checked to stored:
Make all operators at the man-up forklifts responsible for put away within the aisles of the full pallet and box warehouse. This results in shorter waiting times at interim storage locations. The put away time reduced from 5:30:33 working hours to 3:24:49 working hours, a reduction of 2:05:44 working hours.

Problem 6 - Planning of incoming deliveries:
A simulation model shows that planning deliveries more efficiently results in a reduction of the dock to stock time. When the number of incoming products is equally divided over the week and over the day, the result is a reduction of 2:03:23 hours in the dock to stock time compared to the basic model.
A method to control the new planning schedule is the new delivery standard. On this delivery standard it is noted that at least 95% of the orders must arrive on the agreed delivery date. Since suppliers have to sign for this delivery standard, Wavin can use this when suppliers structurally do not deliver their products on the agreed delivery date.

This chapter provides improvements that result in an optimization of the inbound process. Chapter 6 describes the conclusions and recommendations of the research project.

6 Conclusions and recommendations

Chapter 5 describes improvements that result in an optimization of the inbound process. This chapter provides the conclusions and recommendations. Section 6.1 provides answers on the formulated research questions. Section 6.2 describes the recommendations. Finally, in Section 6.3 we give suggestions for further research.

6.1 Conclusions

The main research question of this project is:

How can the inbound process at Wavin be optimized, taking into account staff capacity and available space?

To answer the main research question, we first answer the sub questions.

1. <u>What has been written in the literature about inbound processes?</u>

There is not much relevant literature about inbound processes. Papers that discuss inbound processes are very general and do not provide in-depth information. Golovatova and Zhou (2009) state that there is an enormous gap between theoretical research and practical operations of incoming goods processes. This statement is emphasized by the low number of available papers. Gu et al. (2007) categorize the papers about operational warehouse problems within the following topics: receiving and shipping (4), storage (53), and order picking (67), where the numbers in parentheses represent the number of papers as reviewed by Gu et al. (2007). Research is mainly focused on storage and order picking because it has the largest impact on the performance of warehouses. One of the reasons that may explain the low number of available papers about inbound processes could be that “goods receipt is a deceptively simple process in many warehouses” (Tompkins & Smith, 1998).

2. <u>What is the current situation of the inbound process?</u>

There are four different flows of incoming products: finished goods from the production departments in Hardenberg, products from other factories of Wavin throughout Europe, trade items from external suppliers, and returns from customers & depots. The inbound process begins when trucks arrive at the distribution centre. Trucks are unloaded and products are stored in the receive area. When products are ready to be checked, the products are moved from the receive area to the check area. In the check area, products are registered in the ERP-system and checked on quality and quantity. After that, products are moved to their storage destination. The inbound process ends when the products are available for order picking.

3. <u>What is the current performance of the inbound process?</u>

Currently the goods receipt team cannot reach the goal of 8 picks per man-hour. The maximum picks per man-hour in 2015 were 7.31 in week 37; hence the target has not yet been reached. The average picks per man-hour in 2015 were 6.64. Recall that one pick means a unique product with a given quantity that gets its own destination in one of the storage types.

We indicate several problems that result in underperformance of the inbound process:

- Performance monitoring, the only performance indicator that is directly related to the inbound process is the productivity indicator. This results in a lack of visibility.
- Planning of incoming deliveries, although procurement planners try to create a constant workflow for the goods receipt team, the planning of incoming deliveries is not efficient.
- Staff capacity, there is insufficient staff capacity to perform the inbound process efficiently.
- Available space, there is a lot of traffic in a confined area that lead to safety issues.
- Quality and checking, lots of products must be repacked on other pallets due to the warehouse design. Besides that, operators work in the sequence of the order list that results in much time used for searching products.
- From checked to stored, there is much waiting time when products are already checked and can be put in stock.

4. <u>What can be done to improve the performance of the inbound process?</u>

Based on the outcomes of an experiment in practice and a simulation model, we provide several solutions that help to improve the performance of the inbound process:

- Add one extra operator for unloading trucks (receive activity).
- Make all operators at the man-up forklifts responsible for the put away activity.
- Train operators. Operators must be more flexible in their working activities.
- Use performance indicators to continuously monitor the process.
- Reschedule the division of incoming deliveries over the week.

This brings us to answering the main research question:

How can the inbound process at Wavin be optimized, taking into account staff capacity and available space?

The inbound process of Wavin has to deal with a lot of fluctuation. Currently the inbound process is not designed to deal with peak conditions. This results in a ‘hurry up and wait’ scenario (Tompkins & Smith, 1998). Due to the available space there is no overflow during peak hours. The consequence is that incoming products are frequently stored in areas for outbound deliveries and this leads to intertwined traffic between inbound and outbound operations. Besides that, the daily fluctuations have influence on the goods receipt team. The staff capacity is insufficient to handle the incoming products efficiently. This puts a lot of pressure on the warehouse operators, which may lead them to make mistakes in the check activity. Furthermore, there is much waiting time when products are already checked and can be put in stock.

Based on these problems we test different interventions with an experiment in practice, and we build a simulation model to show the impact of scheduled deliveries. This results in the following five solutions: add one extra operator for unloading trucks, make all operators at the man-up forklifts responsible for the put away activity, train operators, use more performance indicators to continuously monitor the process, and reschedule the division of incoming deliveries over the week. Section 6.2 describes how to implement these solutions.

6.2 Recommendations

Through the use of an experiment in practice and a simulation model we find different improvements. The recommendations in this section are directly linked to the research project. Section 6.3 provides suggestions for further research. Table 6.1 gives an overview of the recommendations. Recall that some of the recommendations are already performed and need to be continued. All recommendations can be implemented and executed in parallel. After the table we describe the (expected) results of implementing each individual recommendation.

Number	Recommendation	Responsibility	Already performed?
1	Add one extra operator for the receive activity	Unit leader warehouse	Yes
2	Make all operators at the man-up forklifts responsible for the put away activity	Unit leader warehouse in cooperation with the team leaders	In progress
3	Train operators	Unit leader warehouse in cooperation with the team leaders	In progress
4	Use of performance indicators	Logistics manager in cooperation with IT department	No
5	Reschedule the division of incoming deliveries	Logistics manager in cooperation with Demand & Supply manager	No

Table 6.1 - Overview of the recommendations

Recommendation 1 - Add one extra operator for the receive activity:

The first recommendation is to add one extra operator from 7:30 AM to 4:00 PM for unloading of trucks (receive activity). This is based on the measurement that 95.2% of the deliveries arrive at the distribution centre before 4:00 PM. When performing this step, the other two skilled operators (instead of one operator) perform the check activity and are disturbed less frequently to unload trucks from 7:30 AM to 4:00 PM. With this recommendation there are constantly two persons to perform the check activity in shifts from 6:00 AM to 2:00 PM and from 2:00 PM to 10:00 PM. The unit leader of the warehouse is responsible for the implementation of this recommendation.

The result of this recommendation is that the operators at the check activity do not have to unload trucks anymore and thus handle products faster. An experiment in practice shows that the average number of working days ago that the current batch at the check activity is unloaded, reduced from 2 working days to 1 working day. Besides that, the operators make fewer mistakes when checking products because the operators can focus on one activity.

Recommendation 2 - Make all operators at the man-up forklifts responsible for the put away activity:

The second recommendation is to make all operators at the man-up forklifts within the aisles of the full pallet and box warehouse responsible for the put away activity. When performing this step, there are maximal six operators responsible for putting away pallets. In the current situation there is one operator responsible, during normal working hours from 07:30 AM to 4:00 PM, for putting away pallets. The operators have more priority for picking outbound delivery and postpone pallet retrieval.

It is important to organize meetings with the operators to emphasize the importance of an efficient inbound process, since the inbound process is a deceptively simple process (Tompkins & Smith, 1998). The unit leader of the warehouse is, in cooperation with the team leaders, responsible for the implementation of this recommendation.

The result of this recommendation is that the put away times are reduced and that the put away activity is less dependent on one person. During an experiment in practice the put away time reduced from 5:30:33 to 3:24:49 working hours, a reduction of 2:05:44 working hours. Also, the average ratio of occupied space in the interim storage zone is reduced from 64% to 35%.

Recommendation 3 - Train operators:

The third recommendation is to train other warehouse operators to perform the check activity. Warehouse operators must be more flexible in performing warehouse activities. This can be done by the use of a training program or yearly refresh course. The unit leader of the warehouse is, in cooperation with the team leaders, responsible for the implementation of this recommendation.

The result of this recommendation is that warehouse operators are more flexible in performing warehouse activities. Besides that, the trained operators can replace operators in case of illness/holidays. Trained operators can also help during peak hours or with overwork on Saturday.

Recommendation 4 - Use of performance indicators:

The fourth recommendation is to use more performance indicators to continuously monitor the process. Because not all performance indicators can be obtained from the ERP-system there is need to modify the ERP-system. Implementation of more performance indicators lead to extra time spent, but will result in more information to optimize the inbound process and reduce the dock the stock times. After successful implementation, we recommend to develop an interface for the visualization of the indicators. Table 6.2 gives an overview of the performance indicators that we recommend to use. The logistics manager is, in cooperation with the IT department, responsible for the implementation of this recommendation.

Time indicators	Productivity indicators	Quality indicators	Utilization indicators
Dock to stock time	Receive productivity	On-time performance	Receive area utilization
Receive time	Check productivity	Check accuracy	Check area utilization
Check time	Check returns productivity	Put Away accuracy	Interim storage utilization
Put away time	Put Away productivity		

Table 6.2 - Overview of the performance indicators

The result of this recommendation is that the inbound process is continuously monitored and the employees can act upon these indicators when problems arise. It is useful for the logistics manager but also for the warehouse operators that are involved with the inbound process.

Recommendation 5 - Reschedule the division of incoming deliveries:

The last recommendation is to reschedule the division of incoming deliveries. We recommend a work group with a procurement planner, logistics specialist, and a goods receipt operator. The main task of this work group is to reschedule the division of incoming deliveries. After successful implementation it is important to monitor the process continuously. Besides that, it is necessary to involve the suppliers, to give insight into the performance of their deliveries. During the research project Wavin imposed new delivery standards. On this delivery standard it is noted that at least 95% of the orders must arrive on the agreed delivery date (with the use of the on-time performance indicator). Since suppliers have to sign for this delivery standard, Wavin can encourage the suppliers when they structurally do not deliver their products on the agreed delivery date. The logistics manager is, in cooperation with the Demand & Supply manager, responsible for the implementation of this recommendation.

The result of this recommendation is a more constant and even workflow. The simulation model shows that the average dock to stock time reduces when the incoming deliveries are more equally divided over the week. When the number of incoming products is equally divided over the week and over the day, the result is a reduction of 2:03:23 hours in the dock to stock time compared to the basic model (from 14:25:49 hours to 12:22:26 hours).

6.3 Further research

This section gives suggestions about further research. The suggestions are linked to the research project but it is necessary to perform more research about the topic. The topics that we suggest for further research are:

- The use of a new storage system to store EURO-pallets. The design of the current warehouse results in much extra handling time due to the racking system. Currently special pallets are needed for the storage of products.
- The effects of different characteristics of the current inbound process, such as the influence of incoming deliveries from small suppliers, structurally deviate from the standard FIFO-rule, or what needs to be redesigned when the number of incoming product grows in the future.
- The design of the outbound process. This includes pick, pack, and ship operations. The scheduling of outbound deliveries has influence on the inbound process.
- The use of a cross-dock area for out of stock and delayed products.

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Appendices

Appendix A - Floor plan of the inside warehouse

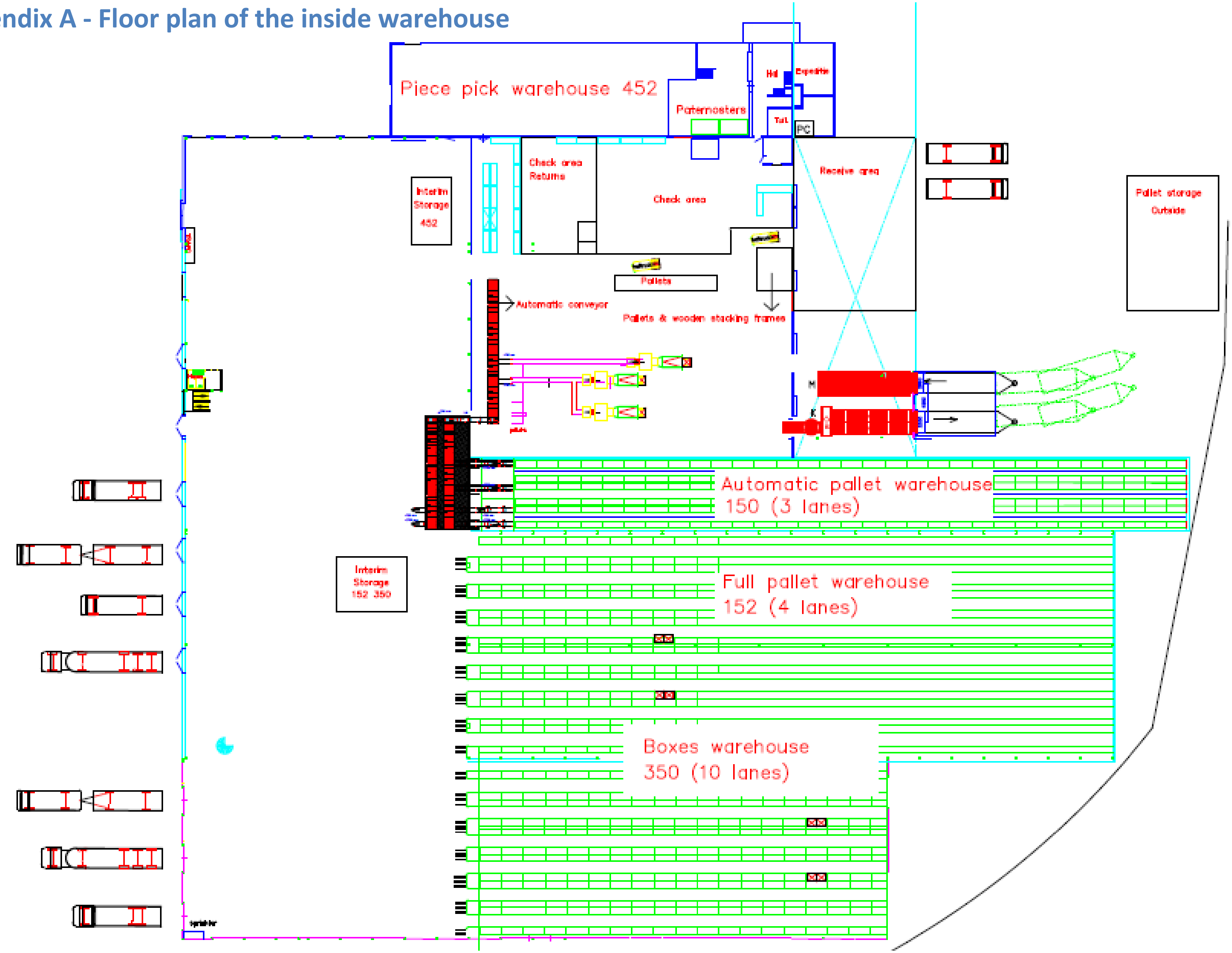

Figure A – Floor plan of the inside warehouse

B

Appendix B – Data of the experiment

Indicator	Time	07-03-2016	08-03 -2016	09-03-2016	10-03-2016	11-03-2016	14-03-2016	15-03-2016	16-03-2016	17-03-2016	18-03-2016	21-03-2016	22-03-2016	23-03-2016	24-03-2016	25-03-2016
		Week 10					Week 11					Week 12				
Receive area utilization	8:00 AM	X	60%	Over-flow	60%	40%	30%	50%	X	40%	40%	100%	40%	20%	70%	30%
	2:00 PM	X	Over-flow	X	80%	80%	80%	60%	X	70%	50%	100%	30%	80%	X	50%
Check area utilization	8:00 AM	X	100%	Over-flow	70%	100%	100%	25%	X	40%	100%	80%	30%	100%	80%	50%
	2:00 PM	X	100%	X	50%	100%	100%	100%	X	40%	10%	25%	60%	20%	X	60%
Interim storage utilization	8:00 AM	X	20%	Over-flow	70%	5%	100%	25%	X	10%	75%	0%	60%	Over-flow	Over-flow	70%
	2:00 PM	X	100%	X	Over-flow	80%	0%	90%	X	Over-flow	80%	40%	Over-flow	Over-flow	X	40%
Number of staging areas used	8:00 AM	X	2	2	2	2	0	0	X	0	0	0	0	0	0	0
	2:00 PM	X	2	X	2	2	0	0	X	0	0	0	0	1	X	0
Number of working days ago	8:00 AM	X	3	3	2	2	2	1	X	1	1	1	1	1	1	2
	2:00 PM	X	3	X	2	2	2	0	X	1	1	1	0	0	X	1
Number of used drop points (max. 46)	8:00 AM	X	12	25	36	16	23	18	X	32	8	24	37	37	40	22
	2:00 PM	X	16	X	28	22	5	13	X	35	23	8	6	32	X	24
Number of occupied man-up forklifts (max. 6)	8:00 AM	X	4	4	4	4	4	3	X	3	4	3	5	5	5	4
	2:00 PM	X	4	X	4	3	5	3	X	3	3	3	4	5	X	3

Table A – Overview of the measurements in week 10 to week 12

X = No measures available, Overflow is in Section 5.3.3 calculated as 100%.

Indicator	Time	28-03-2016	29-03 -2016	30-03-2016	31-03-2016	01-04-2016	04-04-2016	05-04-2016	06-04-2016	07-04-2016	08-04-2016	11-04-2016	12-04-2016	13-04-2016	14-04-2016	15-04-2016
		Week 13					Week 14					Week 15				
Receive area utilization	8:00 AM	NWD	25%	20%	30%	20%	X	5%	40%	60%	60%	40%	5%	20%	20%	50%
	2:00 PM	NWD	60%	50%	30%	20%	X	40%	60%	80%	70%	20%	30%	50%	70%	60%
Check area utilization	8:00 AM	NWD	80%	50%	100%	100%	X	25%	100%	80%	30%	75%	90%	60%	60%	30%
	2:00 PM	NWD	20%	75%	100%	10%	X	25%	50%	25%	20%	50%		70%	30%	40%
Interim storage utilization	8:00 AM	NWD	100%	Over-flow	0%	0%	X	0%	Over-flow	Over-flow	30%	50%	0%	5%	20%	40%
	2:00 PM	NWD	50%	Over-flow	20%	100%	X	25%	Over-flow	0%	20%	100%	50%	Over-flow	40%	Over-flow
Number of staging areas used	8:00 AM	NWD	0	0	0	0	X	0	1	1	0	0	0	0	0	0
	2:00 PM	NWD	0	0	0	0	X	0	1	0	0	0	0	0	0	0
Number of working days ago	8:00 AM	NWD	1	1	1	1	X	1	1	1	2	1	1	1	1	1
	2:00 PM	NWD	1	1	1	1	X	0	1	1	1	1	1	1	1	1
Number of used drop points (max. 46)	8:00 AM	NWD	0	8	2	12	X	16	32	10	30	22	4	9	22	15
	2:00 PM	NWD	30	28	15	29	X	15	40	5	21	3	12	30	18	32
Number of occupied man-up forklifts (max. 6)	8:00 AM	NWD	5	4	4	3	X	4	5	4	5	5	5	4	6	4
	2:00 PM	NWD	1	3	4	4	X	4	4	5	5	4	3	4	5	5

Table B – Overview of the measurements in week 13 to week 15

NWD = Non-Working Day

X = No measures available

Overflow is in Section 5.3.3 calculated as 100%.

Indicator	Time	18-04-2016	19-04 -2016	20-04-2016	21-04-2016	22-04-2016	25-04-2016	26-04-2016	27-04-2016	28-04-2016	29-04-2016	02-05-2016	03-05-2016	04-05-2016	05-05-2016	06-05-2016
		Week 16					Week 17					Week 18				
Receive area utilization	8:00 AM	10%	5%	5%	20%	20%	15%	0%	NWD	20%	80%	60%	80%	80%	NWD	NWD
	2:00 PM	30%	30%	10%	25%	15%	25%	25%	NWD	90%	Over-flow	90%	80%	90%	NWD	NWD
Check area utilization	8:00 AM	30%	80%	10%	20%	20%	0%	20%	NWD	50%	20%	50%	60%	50%	NWD	NWD
	2:00 PM	20%	60%	80%	50%	30%	0%	80%	NWD	60%	30%	70%	30%	80%	NWD	NWD
Interim storage utilization	8:00 AM	0%	10%	40%	0%	5%	5%	0%	NWD	0%	20%	40%	30%	0%	NWD	NWD
	2:00 PM	10%	0%	40%	0%	40%	Over-flow	50%	NWD	100%	60%	40%	Over-flow	50%	NWD	NWD
Number of staging areas used	8:00 AM	0	0	0	0	0	0	0	NWD	0	1	1	0	0	NWD	NWD
	2:00 PM	0	0	0	0	0	0	0	NWD	0	1	0	0	0	NWD	NWD
Number of working days ago	8:00 AM	1	1	1	0	1	0	0	NWD	1	1	2	3	2	NWD	NWD
	2:00 PM	0	1	0	0	0	0	0	NWD	0	1	2	3	2	NWD	NWD
Number of used drop points (max. 46)	8:00 AM	16	15	20	37	11	31	16	NWD	17	27	4	19	25	NWD	NWD
	2:00 PM	19	22	21	7	27	25	17	NWD	29	26	16	25	21	NWD	NWD
Number of occupied man-up forklifts (max. 6)	8:00 AM	6	5	5	4	4	5	4	NWD	4	4	5	6	6	NWD	NWD
	2:00 PM	4	4	3	4	3	5	4	NWD	4	4	3	3	4	NWD	NWD

Table C – Overview of the measurements in week 16 to week 18

NWD = Non-Working Day

X = No measures available

Overflow is in Section 5.3.3 calculated as 100%.

Indicator	Time	09-05-2016	10-05 -2016	11-05-2016	12-05-2016	13-05-2016	16-05-2016	17-05-2016	18-05-2016	19-05-2016	20-05-2016
		Week 19					Week 20				
Receive area utilization	8:00 AM	Over-flow	80%	60%	50%	30%	NWD	30%	40%	20%	X
	2:00 PM	100%	80%	60%	40%	60%	NWD	70%	50%	60%	X
Check area utilization	8:00 AM	40%	60%	30%	20%	80%	NWD	40%	30%	40%	X
	2:00 PM	80%	80%	40%	40%	60%	NWD	50%	40%	20%	X
Interim storage utilization	8:00 AM	30%	50%	Over-flow	50%	Error	NWD	50%	5%	10%	X
	2:00 PM	10%	60%	50%	5%	5%	NWD	100%	20%	80%	X
Number of staging areas used	8:00 AM	0	1	1	0	0	NWD	0	0	0	X
	2:00 PM	1	1	1	0	1	NWD	0	0	0	X
Number of working days ago	8:00 AM	3	4	3	2	1	NWD	1	1	1	X
	2:00 PM	3	3	3	1	1	NWD	1	1	1	X
Number of used drop points (max. 46)	8:00 AM	5	21	12	18	Error	NWD	23	23	16	X
	2:00 PM	21	31	29	27	17	NWD	26	27	23	X
Number of occupied man-up forklifts (max. 6)	8:00 AM	5	5	5	5	Error	NWD	5	5	5	X
	2:00 PM	5	5	6	5	4	NWD	4	3	4	X

Table D – Overview of the measurements in week 19 to week 20

NWD = Non-Working Day

X = No measures available

Error = Breakdown in the ERP-system

Overflow is in Section 5.3.3 calculated as 100%.

Appendix C – Description of the simulation model

Law (2007) describes a system as the operations of various kinds of real-world facilities or processes. To study a system scientifically, we often have to make a set of assumptions about the working of the system. These assumptions are mostly mathematical or logical relationships and "constitute a model that is used to try to gain some understanding of how the corresponding system behaves" (Law, 2007). Figure B shows the different options to study a system. After the figure we explain the different choices that we make.

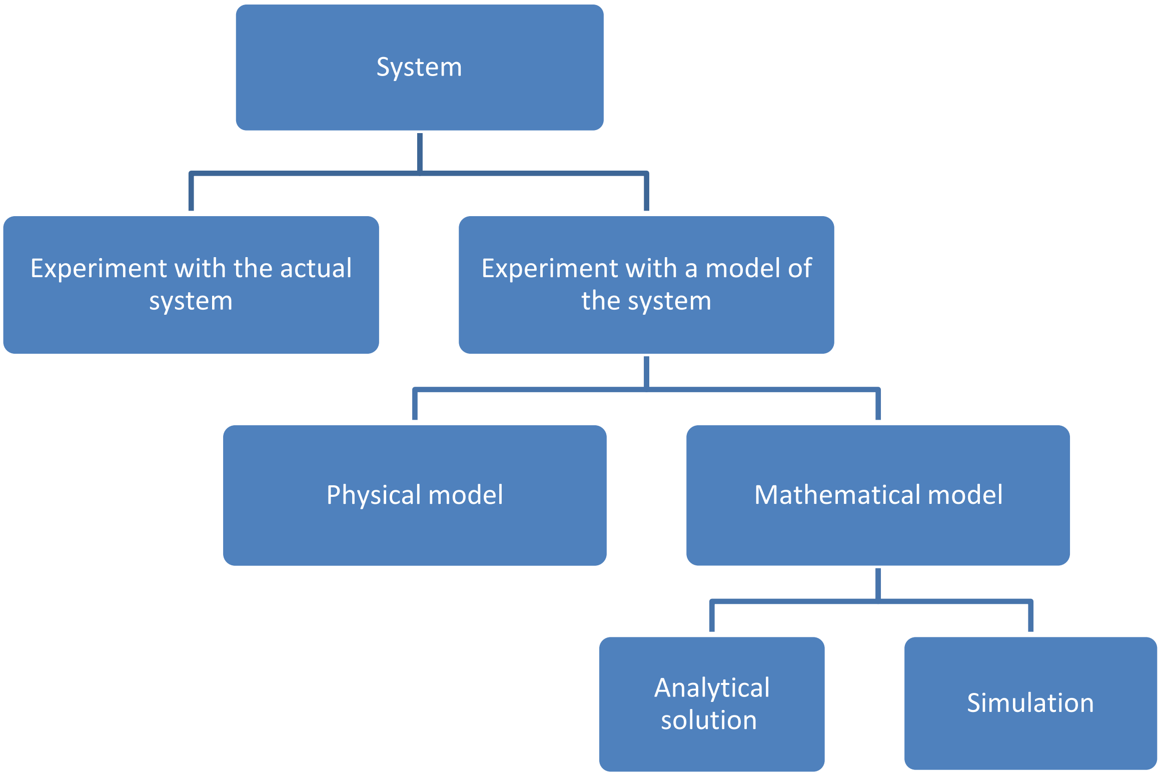

Figure B – Ways to study a system (Law, 2007)

<u>Experiment with the actual system vs. Experiment with a model of the system:</u>

Experimenting with the actual system can be done when it is possible, not disruptive and cost effective to do so. When it is not possible, too disruptive, or too costly to experiment with the actual system it is necessary to build a model of the system. Another reason to build a model of the system could be that we want to study a system that might not even exist. A model is a representation of the actual system, and validation of a model is very important to ensure that the model reflects the actual system. Because it is hard to experiment with the planning of deliveries within the short time period, we need to experiment with a model of the system.

<u>Physical model vs. Mathematical model:</u>

Because we choose for an experiment with a model of the system, the next choice is either to build a physical or a mathematical model. An example of a physical model is a flight simulator. Mathematical models can be used to represent a system in terms of logical and qualitative relationships. Mathematical models can be used to see how the model reacts when these relationships are changed, and thus how the (actual) system would react. Since we do not want to build a physical model, we need to build a mathematical model.

Analytical solution vs. Simulation:
The next choice when we build a mathematical model is how we answer the formulated questions about the system we are trying to represent. If the model is simple enough, we can use an analytical approach to get an exact solution. If the model is complex, it is recommended to study it with a simulation. When modelling the inbound process of Wavin, we have to deal with both variability and complexity. Therefore we choose to build a simulation. Law (2007) describes a simulation by "numerically exercising the model for the inputs in question to see how they affect the output measures of performance".

When we choose for a simulation, the next issue is to determine what kind of dimensions we use to classify simulation models:

Static vs. Dynamic simulation models:
A static simulation model is a representation of the system in which time plays no role and a dynamic simulation model can be used to model a time dependent system, such as a conveyer system in a factory. Since the inbound process is a time dependent system, we use a dynamic simulation model.

Deterministic vs. Stochastic simulation models:
The difference between a stochastic and a deterministic model is the presence or absence of probabilistic components. If there are any probabilistic (i.e. random) components we must use a stochastic model, otherwise a deterministic model. Since we have to deal with a lot of random input, we use a stochastic model.

Continuous vs. Discrete simulation models:
In continuous simulation models the state variables change continuously in time. A car moving from location A to B is an example of a continuous system since the state variables, such as velocity and position, change continuously in time. In discrete simulation models, the state variables change at separate points in time. A simulation of a barbershop is an example of a discrete simulation model since the number of customers in the barbershop (one of the state variables) change only when a customer arrives or departs. Since the state variables of the inbound process change also at separate points in time, we use a discrete model.

Thus, the simulation model we use is dynamic, stochastic, and discrete. The next issue is the probability distribution that we use to model the input variables. We can use the following approaches to model the data:

Trace-driven:
Historical data is directly used in the simulation model. Drawbacks of this approach are that it only simulates historical data, and that there is not always enough data available to design the whole simulation.

Empirical distribution:

The data is used to derive an empirical distribution function. During the simulation, values are obtained from this distribution function by using random numbers. Histograms or other frequency charts can be used to derive the empirical distribution.

Theoretical distribution:

This approach is used to “fit” a theoretical distribution function to the data, and to perform hypothesis tests to determine the goodness of fit. This approach can also be used when no data is available. It is very important to derive a reliable theoretical distribution function that represents reality.

Input distributions

This section describes the data we use in the simulation model. Figure C gives an overview of the model with the different incoming flows and activities.

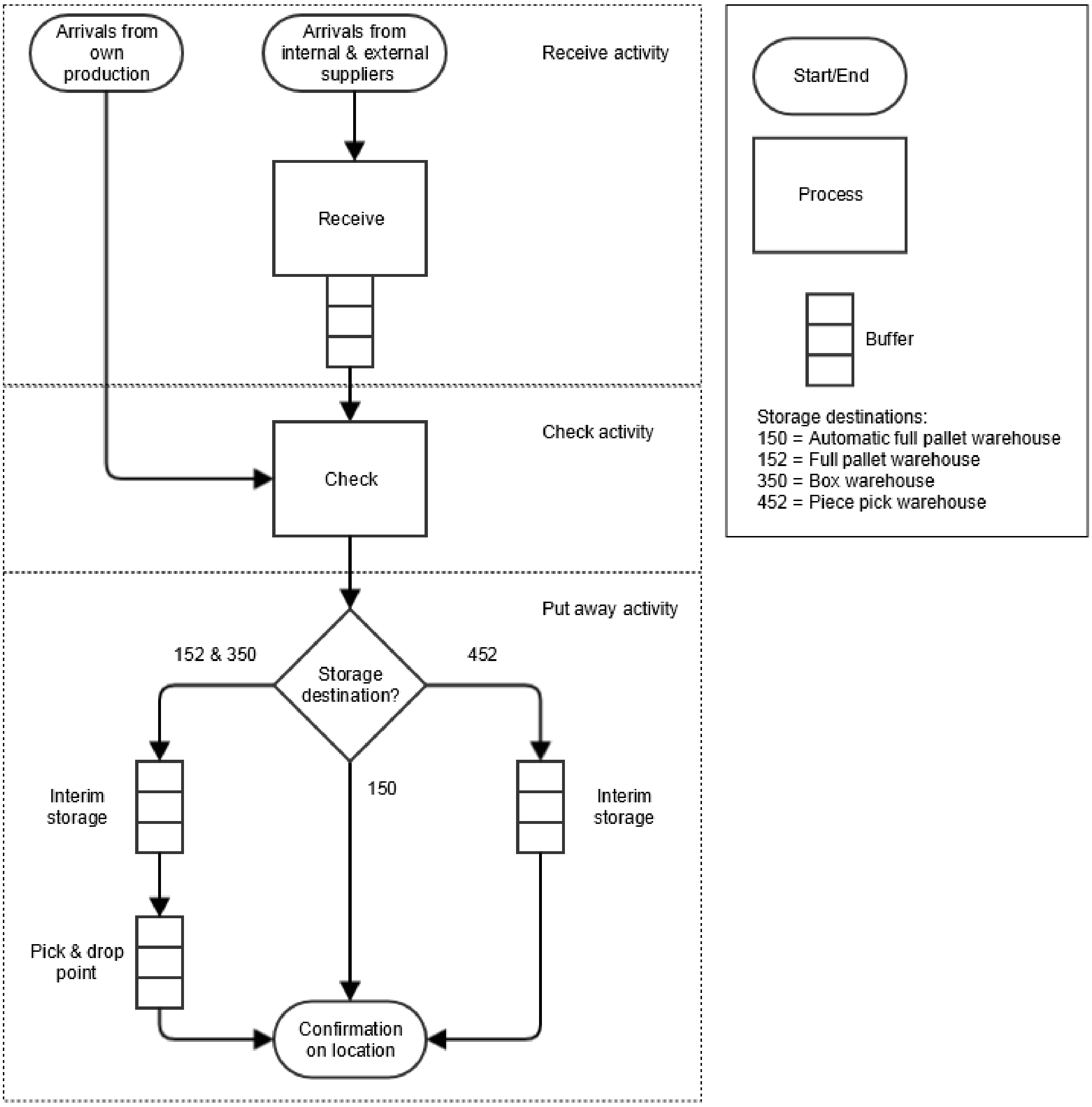

Figure C – Overview of the model

Goods arrival of internal and external suppliers:

A trace of historical data on daily basis is used with information about the name of the supplier and the batch size. The distribution of the deliveries over the day is based on an empirical distribution function based on the measurement of the truck arrival times.

Goods arrival of Larcom (VAL):

Another flow of products are products from Larcom (VAL). According to subject matter experts the VAL products arrive every day at 11:00 AM at the distribution centre and follow the general FIFO-rule. A trace of historical data on daily basis is used for the number of incoming products.

Goods arrival of own production:

Products from own production have priority to all other products, so they are checked first. The arrival of these products is scheduled each day on 9:00 AM and 2:00 PM, according to subject matter experts. 60% (round-up) of the products arrive at 9:00 AM, and 40% (round-down) of the products arrive at 2:00 PM. A trace of historical data on daily basis is used for the number of incoming products.

Receive activity

There is no historical data available about the processing times of the receive activity, so we need to approximate the distribution function in accordance with subject matter experts. We choose a triangular distribution, a continuous probability distribution, with a most probable value of 50 seconds, a minimum value of 10 seconds, and a maximum value of 300 seconds.

Check activity

We use data from the ERP-system for the processing time at the check activity. Since we cannot fit a theoretical distribution function we choose to use a trace of historical data. The variables we use for the check time is the difference between the time of the goods receipt (called MIGO in the ERP-system) and the bin to bin stock transfer (called LT10 in the ERP-system).

The driving time to move products from the receive area to check area is included in the processing time of the check activity. This is a triangular distribution (according to subject matter experts) with a most probable value of 60 seconds, a minimum value of 30 seconds, and a maximum value of 120 seconds.

Put away activity

The put away activities are split up dependent on their storage location:

- Automatic pallet warehouse (storage number 150)
- Full pallet warehouse (storage number 152)
- Box warehouse (storage number 350)
- Piece pick warehouse (storage number 452)

The storage destinations for internal/external suppliers, Larcom VAL, and own production are derived individually.

We use the data of ERP-system to model the put away times. This is the time between the bin to bin stock transfer (called LT10 in the ERP-system) and the confirmation time (ZDW02 in the ERP-system). We use the difference of these times to derive theoretical distribution functions for the processing time at the put away activity, based on their storage location. When it is not possible we to fit a theoretical distribution function, we use an empirical distribution function. Figure D shows the Q-Q plot of the put away times for the automatic pallet warehouse. The Q-Q plot gives a first impression of how well the chosen theoretical distribution fits the empirical distribution. When the Q-Q plot follows more or less the linear line, we use a Chi-Square test to check if the (expected) theoretical distribution function is the right one. The significance level that we use is 0.05. If the probability value of the Chi-Square test is below 0.05, we reject the theoretical distribution. Otherwise, we accept the theoretical distribution function.

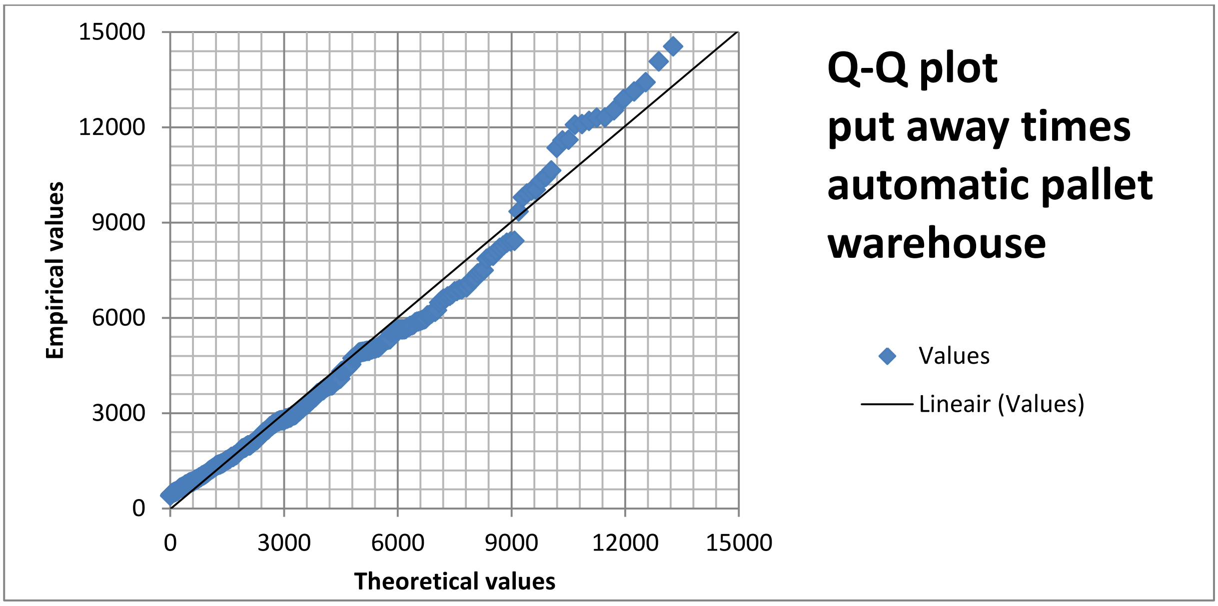

Figure D – Q-Q plot of the put away times for the automatic pallet warehouse

Staff capacity

We simulate the man-hours of the two shifts from 6:00 AM to 2:00 PM and from 2:00 PM to 10:00 PM, without breaks.

Each product in the simulation model has the following attributes:

Name	Type	Description
Arrival time	Time	Arrival time of the product
Confirmation on location time	Time	The time a product is available for order picking
Identification number	Integer	To track the number of items
Processing time check	Time	Processing time of the check activity
Processing time dock to stock	Time	Processing time from dock to stock
Processing time put away	Time	Processing time of the put away activity
Processing time receive	Time	Processing time of the receive activity
Storage Type	Integer	Storage type: 150/152/350/452
Supplier	String	Name of the supplier

Table E - Attributes of a product

We summarize the data that we use in Table F.

Type	What?	Description
Goods arrival	Internal/External	Quantities based on a trace of historical data Arrival times based on an empirical distribution
	Larcom-VAL	Quantities based on a trace of historical data Every day at 11:00 AM
	Own production	Quantities based on a trace of historical data Every day at 9:00 AM (60%) and 2:00 PM (40%)
Receive activity	Time of unloading a delivery	Triangular distribution with a most probable value of 50 seconds, a minimum value of 10 seconds, and a maximum value of 300 seconds.
Check activity	Time between MIGO <> LT10	Empirical distribution of the check times. The driving time to move products from the receive area to the check area is also added. This is a triangular distribution with a most probable value of 60 seconds, a minimum value of 30 seconds, and a maximum value of 120 seconds.
Put away activity	Time between LT10 <> ZDW02	When possible a theoretical distribution function, otherwise an empirical distribution function. The put away time depends on the storage type: 150 – Automatic full pallet warehouse 152 – Full pallet warehouse 350 – Box warehouse 452 – Piece pick warehouse

Table F - Data of the simulation model

<u>Assumptions:</u>

- Walking distances are excluded.
- Returns and the packaging line are excluded.
- Staff illness is neglected.
- Forklifts never fail.
- All items that are not processed during the day are processed during the next day.
- Capacity of a process is fixed.
- There is unlimited capacity in the storage zones.
- 5 workdays a week, no work on Saturday.
- 1 line in the data counts as 1 incoming pallet.

Flowcharts

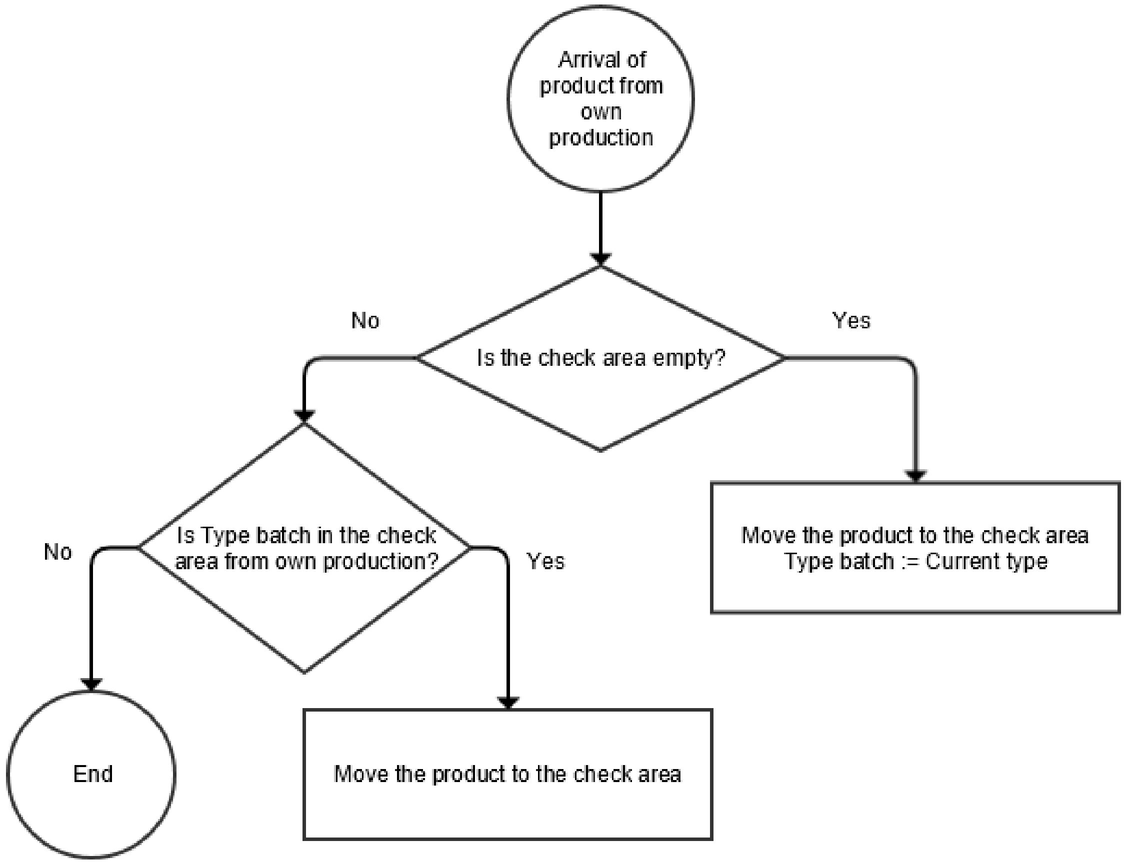

Figure E – Flowchart of the arrival of a product from own production

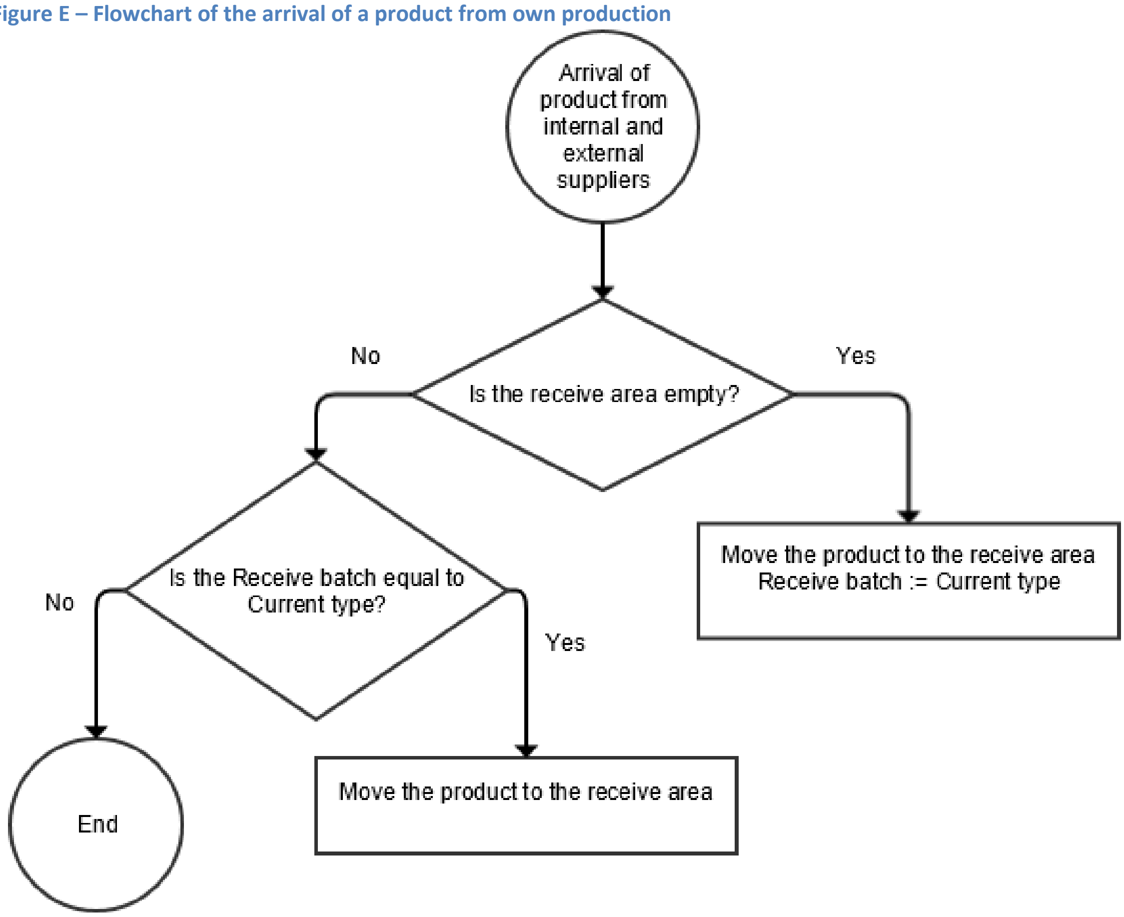

Figure F – Flowchart of the arrival of a product from internal and external suppliers

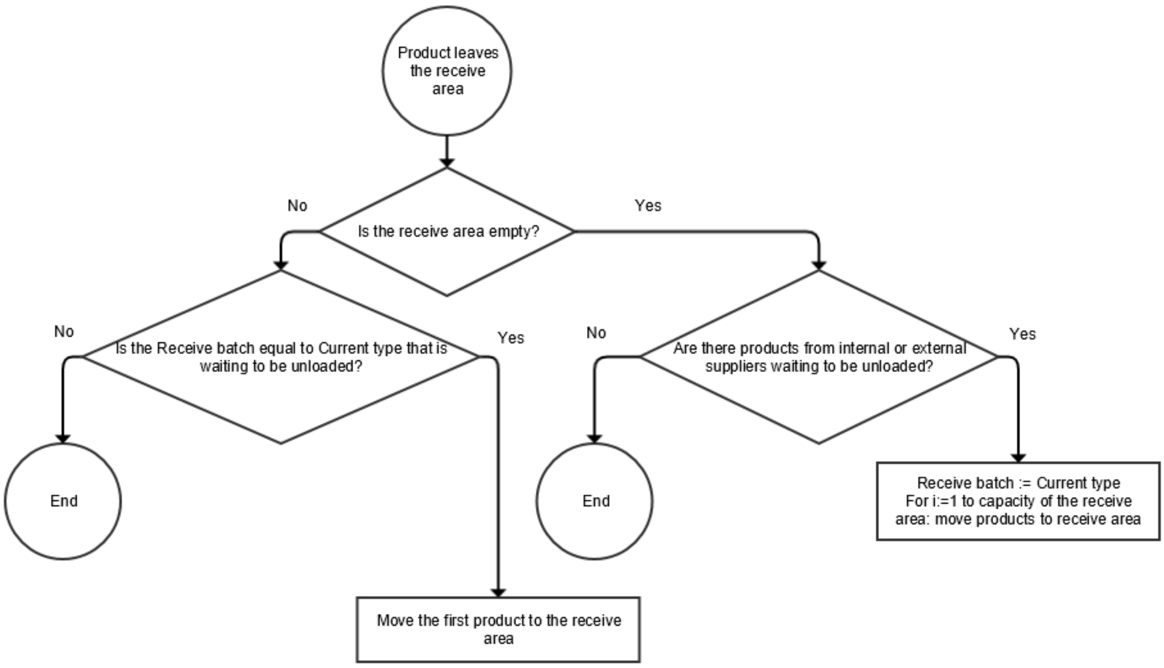

Figure G – Flowchart of the exit at the receive area

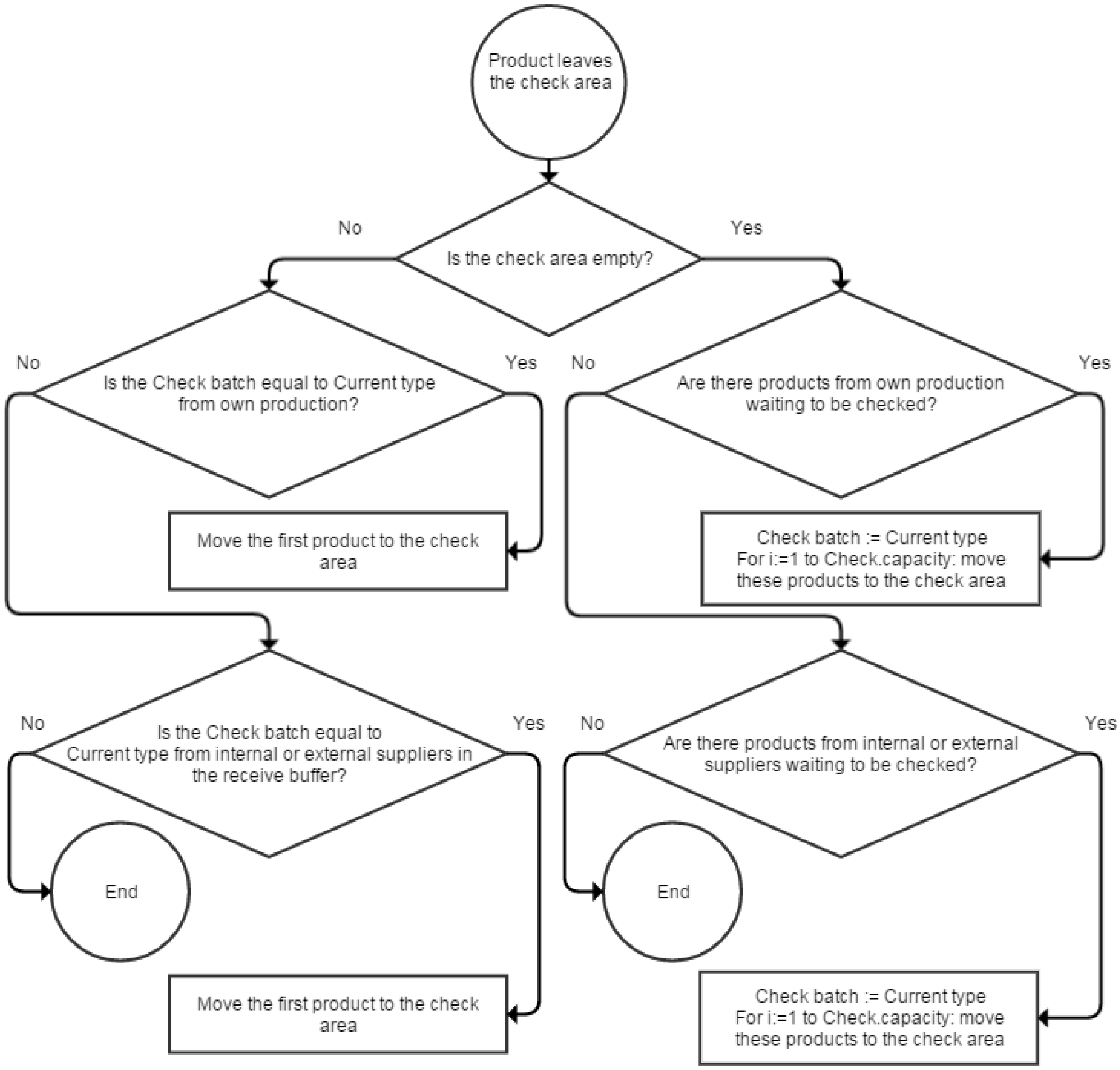

Figure H – Flowchart of the exit at the check area

Number of replications and run length

We use the central limit theorem to construct confidence intervals and determine the number of replications. The run-length we use is 65 days, which is the same as the historical input data. We choose to use a new random number stream in each replication to get independent replications. We use the following formula:

$$\frac{t_{n-1,1-\frac{\alpha}{2}}\sqrt{\frac{{S_n}^2}{n}}}{\bar{X}} < \gamma' \ (equation\ 1)$$

With,

$t_{n-1,1-\frac{\alpha}{2}}$	= Student's t-distribution for n-1 degrees of freedom and a probability of 1-(α/2)
${S_n}^2$	= Sample variance over n replications
n	= Current number of replications carried out
$\bar{X}_n$	= Cumulative mean of the output data
γ'	= Corrected target value

First, with a relative error of $\gamma = 0.05$ we calculate the corrected target value γ':

$$\gamma' = \frac{\gamma}{(1+\gamma)} = \frac{0.05}{(1+0.05)} \approx 0.0476 \ (equation\ 2)$$

We perform replications until the width of the confidence interval, relative to the average, is sufficiently small. We choose a confidence interval of 95% ($\alpha = 0.05$). For the worst case, we calculate the number of replications with equation 1. The number of replications that we need before the value in equation 1 is below 0.0476 is n = 16.

n	12	13	14	15	16
Average	49392.46	47487.49	47654.2	46712.75	52101.17
Average over n	50382.45	50159.76	49980.8	49762.93	49909.07
Variance over n	22496817	21361378	20251953	19566364	18663820
T.INV-value	2.200985	2.178813	2.160369	2.144787	2.13145
t.value * √(S²/n)	3013.61	2792.948	2598.348	2449.591	2302.053
t.value * √(S²/n) /Average over n	0.059815	0.055681	0.051987	0.049225	0.046125
< y' ?	FALSE	FALSE	FALSE	FALSE	TRUE
y'	0.047619	0.047619	0.047619	0.047619	0.047619

Table G - After n=16, the margin of error is smaller than γ'

So, we need 16 independent replications in the simulation model.