Layout Optimization at Scania Logistics Netherlands

Master thesis of B.E. Stoffelsen

SCANIA

UNIVERSITY OF TWENTE

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SDG

Foreword

This report is the result of my graduation project at Scania Logistics Netherlands in the context of obtaining my master degree for Industrial Engineering & Management at the University of Twente. I owe my gratitude for achieving this to many people.

I would like to thank everyone who contributed to this study. Firstly, I would like to thank my University of Twente supervisors, Peter Schuur and Matthieu van den Heijden. Peter, you really inspired me with a great many ideas and Matthieu, thank you for adding more detailed feedback, which helped me greatly to refine my work.

Equivalently important were my Scania supervisors and colleagues. Firstly, I want to thank Scania supervisors Jon Grasmeijer and Frans van den Berg. Jon I learned a lot from your energy and vision on translating theory to practice within Scania. Frans, your eye for detail and keeping an eye on not only the work, but also personal well-being were highly appreciated. In addition: You both have (probably unintentionally) thought me some fascinating insights in company politics, also my thanks for that.

I would also like to thank my day-to-day colleagues, especially Hessenpoort colleagues Karin, Jens, Casper, Paul, Marie-Louise and Sven for the pleasant working environment, the conversations and your roles as sparring partners for my work and ideas. I could and should thank so many more people. Those who go unmentioned, thank you for your professional support and a wonderful atmosphere!

My family and friends could not go unmentioned, my parents in particular. I am truly grateful to my parents for raising me and always encouraging me to study and get the best out of my talents. Thank you so much!

Bart Stoffelsen

Management Summary

Problem

Scania Logistics Netherlands (SLN) produces Knock Down trucks, which can be described as truck building packages. SLN picks parts and subassemblies of these trucks and sends them to simple foreign facilities. They assemble the trucks and bring them to the end-customers. SLN has 2 facilities: Hessenpoort and Staphorst. SLN constructed their layouts quickly and due to frequent changing plans applies various ad hoc changes. As a result, the layouts contain various illogical elements. Hence, this study's main question is:

"How can SLN redesign its layouts to reduce its material handling costs?"

This study offers:

1. A structured approach to the facility layout problem
2. A layout tool, which combines two popular layout heuristics
3. A unique simulation based approach to flow and capacity determination
4. Various practical recommendations:
   a. Low hanging fruits— Relatively easy to implement, yields small savings
   b. Middle hanging fruits— Cost effort, but yield larger savings
   c. High hanging fruits—Hard to implement, can yield large saving

A structured layout approach

This thesis offers a structured layout approach based on Systematic Layout Problem (SLP) (Muther, 1968) and adds more modern computer based heuristics. SLP consist of 3 basic steps to create a layout design:

1. ***Analysis*** Activities, material flow quantities between activities and required capacity per activity
2. ***Search*** Trade-off modifying considerations and practical limitations to create layout alternatives.
3. ***Evaluate*** Evaluate the layout and choose the best option.

SLP can help Scania to standardize its layout procedures. Facility planners can use SLP to make up a checklist which indicates (a) if they have spent sufficient attention to each step of a layout analysis/redesign and (b) How to improve their current procedures.

A layout tool, which combines two popular layout heuristics

For this study, we created a facility layout tool, which combines two facility layout heuristics. It first uses a Simulated Annealing heuristic, which tests over a thousand "rough" layout alternatives per second. The planner then picks the desired option and adjusts non practical characteristics. In the second heuristic, the planner applies feasible department exchanges to this layout. The second heuristic tool accommodates this by computing in each step/for each layout the total relevant costs.

Such a tool can help Scania not only to create layouts by complete trial and error, but also to consider many theoretical solutions and to speed up the creation, testing and adaption of practical solution.

A unique simulation based approach to Flow and Capacity determination

Our Order Pick Simulation offers, as far as we can find, a new approach to flow-determination and capacity setting for a layout problem. This simulation logic gives SLN more grip on its order pick processes and its storage areas. Advantages include

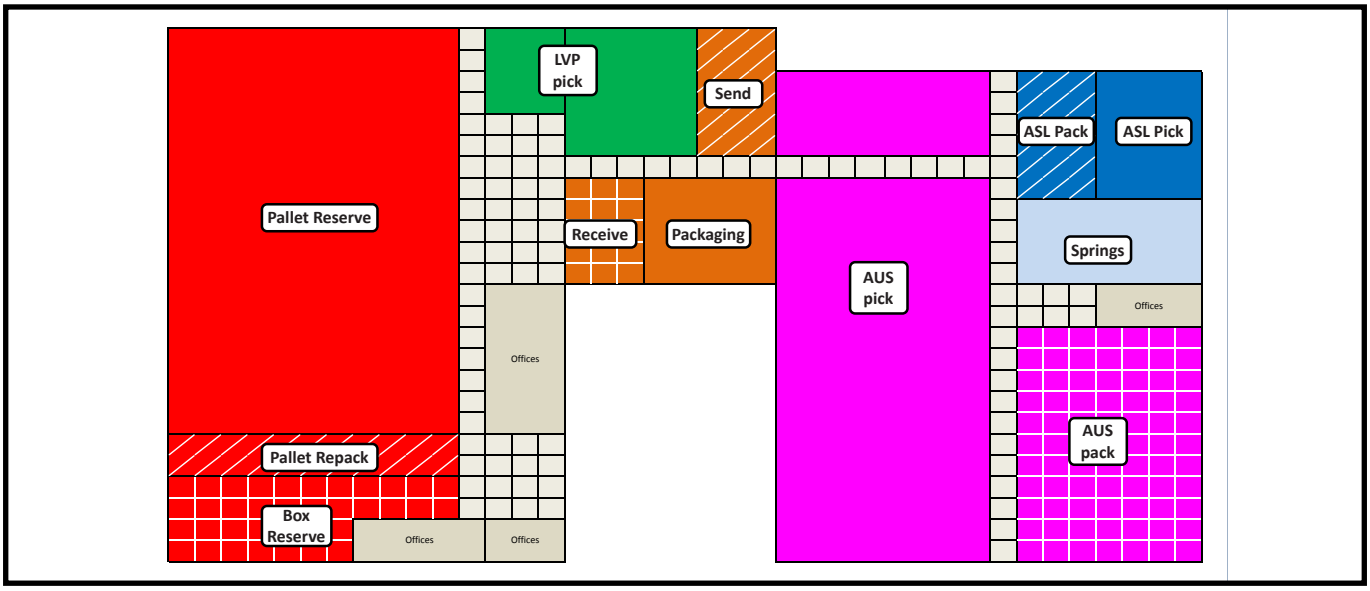
- It is a collection of part information, which is unique to Scania.
- It visualizes material flows. This adds to the credibility towards users.
- It gives an over-time analysis of materials flows and capacities, allowing the user to work with averages, higher decimal values and see the long term effect of actions on order pick and storage areas.

In addition, scholars and practitioners alike can benefit from our simulation approach. It firstly improves on analyses based on guesses and feeling. Secondly, it improves on numerical analyses, because such methods can consider e.g. long-term effects, variability and output behaviour.

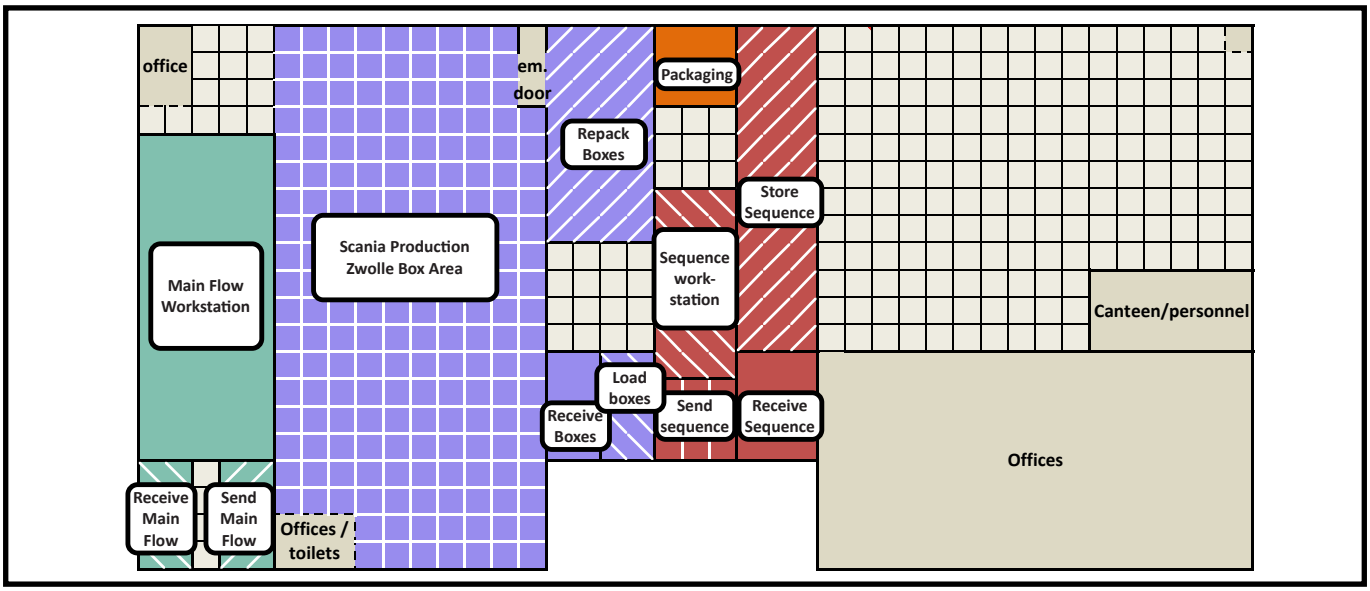
Theoretical layouts

Based on the upcoming situation, where the Boxes go to SLN, we show the following layouts:

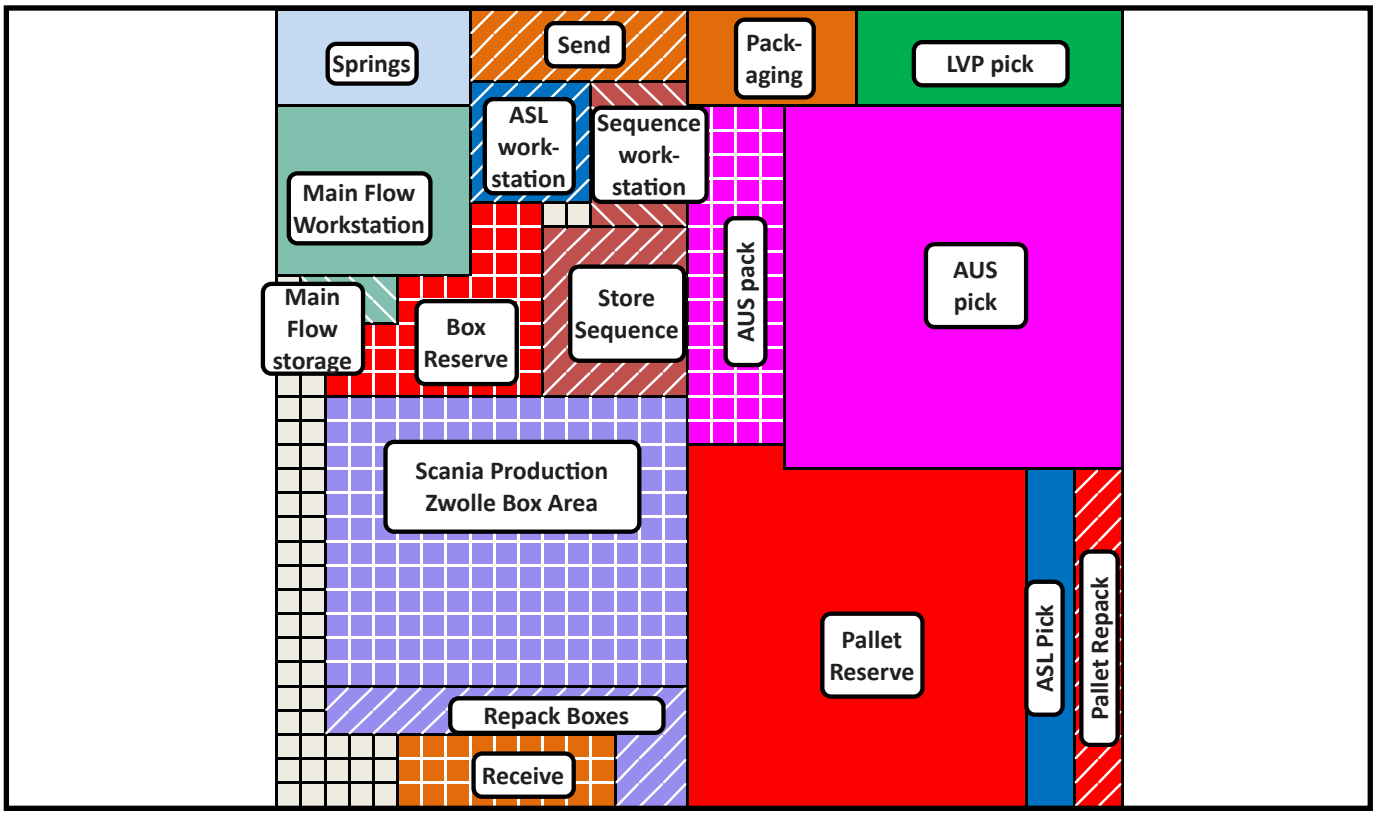
- Hessenpoort, where we advice placing AUS pick
- Staphorst, where we advice to place the Scania Production Zwolle Boxes
- A Green Field facility, which has 6% lower costs than when SLN optimizes the planned situation. Costs of changing the current situation make this situation more desirable.



Hessenpoort



Staphorst



Green Field

Conclusions & Recommendations

This study tests 3 'new' scenarios of which one is a Green Field situation. The Green Field facility offers the best total costs. It saves ca. 20% internal handling costs, ca. 40% capacity costs and ca. 8% external transport costs. We conclude this solution also offers a process-reengineering, which avoids large change costs, but we urge Scania to carefully plan its timing, because building a new facility before big changes in functions/processes means high changing costs counteract the savings (in both operational and change costs) of this new facility.

On short/middle term time, we propose the following recommendations to SLN:

Low hanging fruits:

- Place the LVP in the upper left part of Hall 2 and the upper right part of Hall 1 at Hessenpoort
- Fill the Pallet Reserve Area in Hessenpoort as much as possible from the docks' side

Middle fruits:

- Discard kanban at picking areas and supply to these areas based on their short term demand
- Place AUS at Hessenpoort and the Zwolle Boxes at Staphorst
- Send as many as possible full material units

High hanging fruits

- Adapt the ERP system to be able to effectively handle warehousing decisions and handling
- Apply zoning to storage- and picking areas

List of meanings & abbreviations

ASL	Heavy pick parts (>10 kg)
AUS	Picking parts of ‘average’ weights
KD	Knock Down
LVP	Low Value Parts
SLN	Scania Logistics Netherlands
External Sequence	Process of repacking expensive, dedicated parts from external suppliers
Main Flow	Process of repacking expensive, dedicated parts from internal suppliers
Zwolle Boxes	The Box Reserve Area of Scania Production Zwolle will move to SLN

Table of contents

1. Introduction

This is the master thesis of Bart Stoffelsen and serves to obtain a master degree in Industrial Engineering & Management at the University of Twente. This thesis is a result of my study at Scania Logistics Netherlands into the facility layout designs at two locations: Hessenpoort and Staphorst.

Chapter 1 gives a short company and problem introduction. Section 1.1 introduces Scania Logistics Netherlands and the Knock-Down Trucks. Section 1.2 introduces our layout problem, Section 1.3 treats our research methodology and Section 1.4 our deliverables.

1.1 Scania Logistics Netherlands & the KD production

Scania Logistics Netherlands (SLN) is a new Scania subsidiary and produces Knock Down (KD) trucks. Scania normally completely assembles its trucks at complex locations. KD trucks are an exception and can be described as truck building packages. SLN picks and packs parts and subassemblies of these trucks and sends them to simple foreign facilities. They assemble the trucks and bring them to the end-customers.

SLN started producing KD trucks two years ago and had to create these capabilities, it hired facilities at industrial area Hessenpoort and in Staphorst. This fast build-up means SLN focussed mainly on creating output capacity and gave less attention to efficiency. In addition, SLN is a young company and the KD market is uncertain and still developing. This causes SLN to change plans frequently. These factors caused costs to rise drastically. Therefore SLN is looking for means to reduce its costs.

1.2 Problem introduction

Section 1.1 mentions the quick SLN build-up. This section gives a short problem introduction, whereas Chapter 3 provides a more thorough problem analysis. Amongst others, SLN constructed the facility design of Staphorst and Hessenpoort quickly. Also, due to the frequent changing plans, SLN applies many ad hoc layout changes. Even now, various changes are coming up, which will affect the layouts.

As a result, the layouts contain various seemingly strange elements. Workstations with few flows going to and from them have central facility locations, material flows make u-turns and capacity allocation does not always seem apt. We therefore assume redesigning the layout can reduce travelling distances and define our main question as:

"How can SLN redesign its layouts in order to reduce its material handling costs?"

Solving a facility layout problem reduces travelling distances. This means (a) eliminating waste in terms of material flows and (b) reducing personnel/transport costs. Tompkins (2010) argues that effective facility planning reduces handling costs by up to 30%. Also SLN can learn from our findings apply this study's knowledge to later situations and decisions. To solve this question, the study answers 7 research questions as will be treated in Section 1.3.

1.3 Solution approach

To answer its main question and to construct redesign proposals, this study answers a set of questions. This section defines these questions.

Chapter 2: Activities and organisation

Chapter 2 describes the current situation at SLN and answers research question 1:

"Which activities does SLN perform and how are these activities organized?"

Chapter 2 analyses what/ how SLN delivers to its customers and considers both current and future activities.

Chapter 3: Problem analysis
Chapter 3 analyses observed issues at SLN Chapter 3 answers research question 2:

"What are the main issues associated with SLN's current processes?"

Chapter 4: Literature Review
Relevant literature can give insight in how to solve a layout problem. Therefore research question 3 is:

"Which scientific literature is needed to solve the facility layout problem at SLN?"

Chapter 4 looks into scientific literature and seeks approaches and insights we can use in order to get better insight in and tools for solving layout problems. Chapter 4's output is a facility layout methodology.

Chapter 5: Activities and transport flows
Current and future activities cause flows within and between the facilities. Chapter 5 analyses the current and future flows at SLN. Research question 4 is:

"Which activities will SLN execute and which material flows will they create?"

To answer this question, Chapter 5 applies information/data from Chapters 1-4. We look at current and future processes and at processes that can improve the current material flows. One evaluation method is a Monte Carlo simulation, which yields, given demand quantities and truck types, a total expected amount of flows from/to activities per day. Chapter 5 results in a relationship diagram (as introduced by Chapter 4)

Chapter 6: Necessary capacity
To create feasible layouts, Chapter 6 determines all capacity-requirements. Research question 5 is:

"How much capacity does each activity require and how does this relate with SLN's total capacity?"

Chapter 6 applies methods from literature and again the Monte Carlo Simulation, in dialogue with managers and employees of SLN. This results in a space relationship diagram (as introduced by Chapter 4).

Chapters 7: Layout redesign
Chapters 7 develops layout alternatives and measure the qualities of the original solution and these alternatives. To do so, the chapter establishes restrictions to which a layout has to adhere and consequently develops and measures alternatives based on methods found in Chapter 4. Research question 6 is:

"How can SLN redesign its layouts and how do the changes affect SLN's performance?"

Chapter 7 answers this question by applying methods and knowledge from literature, in dialogue with SLN managers and employees. Chapter 7 gives layouts for Staphorst, Hessenpoort and a fictional Green Field situation.

Chapter 8: Conclusions & recommendations
Chapters 8 summarizes this study; concludes on the found solutions and gives SLN practical recommendations.

1.4 Deliverables

To successfully finish our project, we define its deliverables and timeframe. (1) Scania can execute our recommendations during the Christmas holidays; (2) We deliver (a) a distibution of activities between locations and (b) a standardized methodoloy and a set of tools Scania can apply and learn from.

1.4.1 Potential execution during Christmas holidays

To execute layout changes, SLN must not produce, which is the case during weekends and holidays. The weekend seems fairly short to execute larger changes. The deadline for this master thesis is at the end of the 3rd quartile or at the start of the 4th quartile, so the first holidays after our thesis are the Christmas holidays. So we set potential project execution at Christmas holidays 2013/2014.

1.4.2 Deliverable I: Layouts

The first deliverable of our project is a facility layout. We present two levels of detail:

1. Distribution of activities between facilities
2. Layout per facility

1.4.3 Deliverable II: Methodology & tools

The block and detailed facility layouts are not the only deliverables of this project. SLN plans to leave Hessenpoort and Staphorst and to move to a central location in a few years. In that case our layouts itself have little value.

Our methodology and used tool however can be of value again. While probably some adjustments must be made for each specific situation, the line of reasoning of each step and more specific layout tools can be reused when designing a new layout.

2. Scania, SLN and its processes

Chapter 1 introduces our facility layout problem. Chapter 2 gives an overview of Scania & SLN and explains the processes on system level, facility level and part type level and introduces future changes that affect the layouts of Hessenpoort and Staphorst. This chapter answers the following research question:

"Which activities does SLN perform and how are these activities organized?"

2.1 Scania

This section introduces Scania in general. It discusses Scania's markets, introduces lean thinking within Scania and explains Scania's temporary employment strategy.

2.1.1 Scania and its markets

Scania is a Swedish multinational producer of commercial trucks, busses and engines. In 2012 Scania sold 67,000 vehicles and employed 38,500 employees worldwide. Scania distinguishes itself by applying modular design: All trucks consist of similar modules, which provide a high amount of standardization.

Europe is Scania's home and largest market with 30.000 vehicles sold in 2012. In addition, Scania sold 20,000 vehicles in America, 7,000 in Eurasia, 10,000 in Asia and 4,000 in Africa/Oceania. The 2012 annual report mentions attempts to develop new markets, Asian markets in particular. To do so, Scania builds simple assembly facilities in these countries. SLN sends parts and subassemblies for the trucks to these facilities and assembles them there. Section 2.2 explains in more detail this KD process.

2.1.2 Scania Production System

Lean thinking is deeply imbedded in Scania, e.g. frequent mentioning in annual reports (Scania, 2013) exemplifies this. In 1989 visiting and learning from Toyota was the start of the so-called Scania Production System. Examples of implementations are factories running on takt time, standardization of production steps and extensive appliance of lean paradigms such as Poka Yoke and Kaizen.

2.1.3 Employees

In 2012, Scania employed 38,500 employees (Scania, 2013). Especially in production environments, most of them are temporary employees. At SLN, 69% of employees and 66% of FTE hours are temporary hired (Scania, 2013-2).

To manage temporary employees, Scania hires employment agency Randstad. Randstad contains a so-called "flex pool", of which Scania gets more employee-hours when it is busy and employ employees for fewer hours when it is less busy. The arrangements with Randstad allow Scania to manage the number of working hours on a relatively flexible manner. This improves Scania's volume flexibility.

2.2 Scania Logistics Netherlands and its knock-down trucks

Scania completely assembles most trucks at complex locations. Knock-Down (KD) trucks are an exception and can be described as truck building packages. SLN picks and packs the parts and subassemblies of the KD-trucks and sends them to simple foreign facilities. These facilities assemble the trucks and bring them to their end-customers. Advantages of KD include:

- Sharply reduces the import duties
- Better service for local markets at 'guest countries'.
- Provides faster access to new markets

This concept is not new. Already early in the twentieth century, Ford applied forms of KD production. In his autobiography Henry Ford (1922) mentions:

"We used to assemble our cars at Detroit, and although by special packing we managed to get five or six into a freight car, we needed many hundreds of freight cars a day. Trains were moving in and out all the time. Once a thousand freight cars were packed in a single day. A certain amount of congestion was inevitable. It is very expensive to knock down machines and crate them so that they cannot be injured in transit—to say nothing of the transportation charges. Now, we assemble only three or four hundred cars a day at Detroit—just enough for local needs. We now ship the parts to our assembling stations all over the United States and in fact pretty much all over the world, and the machines are put together there. Wherever it is possible for a branch to make a part more cheaply than we can make it in Detroit and ship it to them, then the branch makes the part." (Ford 1922, p150)

Scania also produces KD-trucks for a longer time. For several decades, Scania Latin America created small quantities of KD-trucks. Two years ago, Scania changed its strategy: Scania scaled up capacity and let KD become a major production strategy. This strategy is mainly deployed in Holland by the new subsidiary Scania Logistics Netherlands (SLN). So far, SLN is only responsible for KD production.

Since KD was new to Scania Holland, SLN had to create production capacity and capabilities: It opened facilities at industrial area Hessenpoort and in Staphorst. Hessenpoort is SLN's current headquarter. A quick build up meant SLN's main focus has been creating output capacity, while costs have risen drastically.

2.3 KD system overview

This chapter already established SLN produces KD-trucks, which are truck building-packages. SLN picks and sends parts from Holland. SLN sends finished pallets to Seacon in Meppel. Seacon is a logistic service provider, which stuffs the pallets in sea containers and sends them to the Port of Rotterdam, from where the containers travel to their destination-countries.

The process from order-confirmation to delivery takes 21 days. Based on customer orders, SLN makes a rough production planning and communicates it to relevant locations. Based on this planning, packing engineers design a container layout, which Seacon uses to fill the containers. These layouts prescribe (a) which pallet to put where in which container and (b) the contents of each pallet. After the layout is ready, SLN releases the batch, prints all pallet labels in Staphorst and spreads them to all locations.

Based on container layout and production planning, suppliers deliver the relevant parts to SLN and the locations start picking and packing the batch. They send the pallets to Seacon, where they arrive at day 21. SLN has two facilities, one at industrial area Hessenpoort in northern Zwolle and another in Staphorst. They process most parts for the customers' KD trucks.

Scania Production Zwolle, the Dutch main truck facility, builds KD sub-assemblies and Scania's paint shop in Meppel processes painted KD parts. Both send the parts directly to Seacon. Because SLN is a separate organisation and has to buy these products, they can be regarded as suppliers. Figure 2.1 depicts the relevant locations and their in-between transport streams.

One can distinguish order pick parts and dedicated parts, i.e. pre-assigned to a specific truck. Generally, SLN pick and packs the non-dedicated parts.

Order pick parts, from light to heavy:

- ***LVP*** Low value parts such as nuts and bolts.
- ***AUS*** "Average" pick parts, weighing < 10kg.
- ***ASL*** Parts weighing > 10kg, not pick-able by hand,
- ***Springs*** Heavy picking parts, which have a separate station

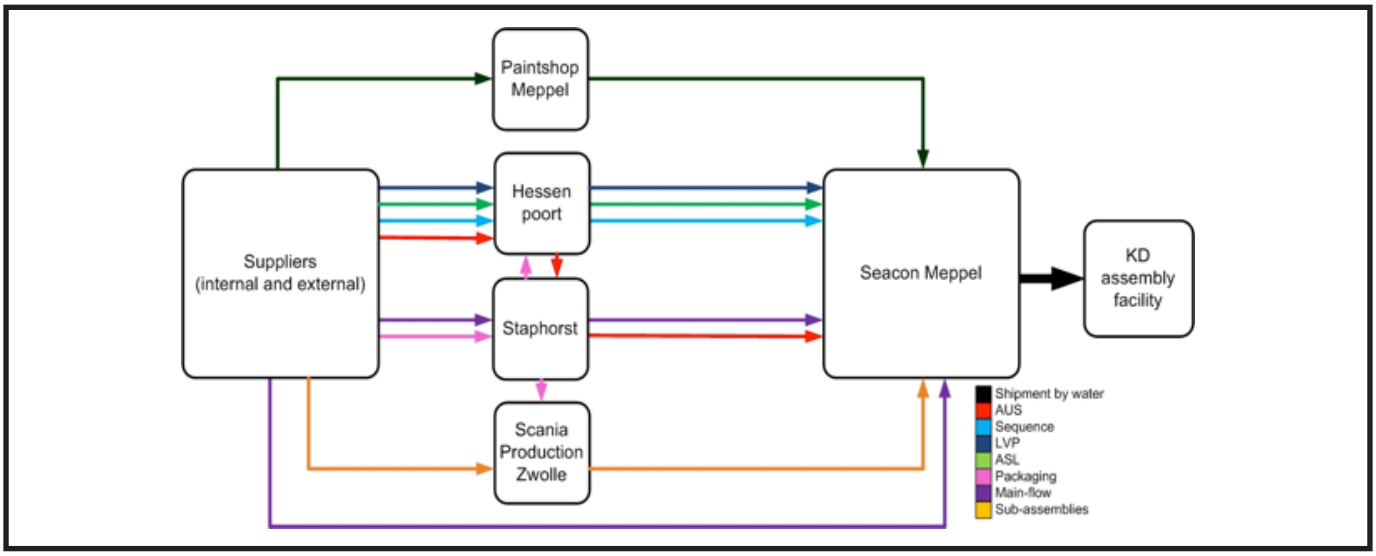


Figure 2.1 KD system overview

Dedicated parts

- ***External Sequence*** Externally supplied parts for a specific truck. SLN repacks them. Examples include tiers and petrol tanks.
- ***Main Flow*** Internally supplied parts for a specific truck. SLN repacks them. Examples include engines and axles.
- ***Sub-assemblies*** Complex assemblies, put together before sent to Seacon (Supplier- out of scope)

2.4 Proces description

This section describes the materials flows within Hessenpoort and Staphorst: AUS, LVP ASL, Sequence, Main Flow and Packaging.

2.4.1 Order pick processes

This section describes the materials flows for order pick processes.

LVP- Low Value Parts

LVP parts are small, relatively cheap parts such as nuts and bolts. Its reserve areas are the Hessenpoort Pallet Reserve Area and Box Reserve Area, which supply to a pick area. Employees pick the parts and put them in pallets and forklifts bring the completed pallets to a loading area. LVP Picking uses kanban: When a box is empty, it requests a new one from the reserve area.

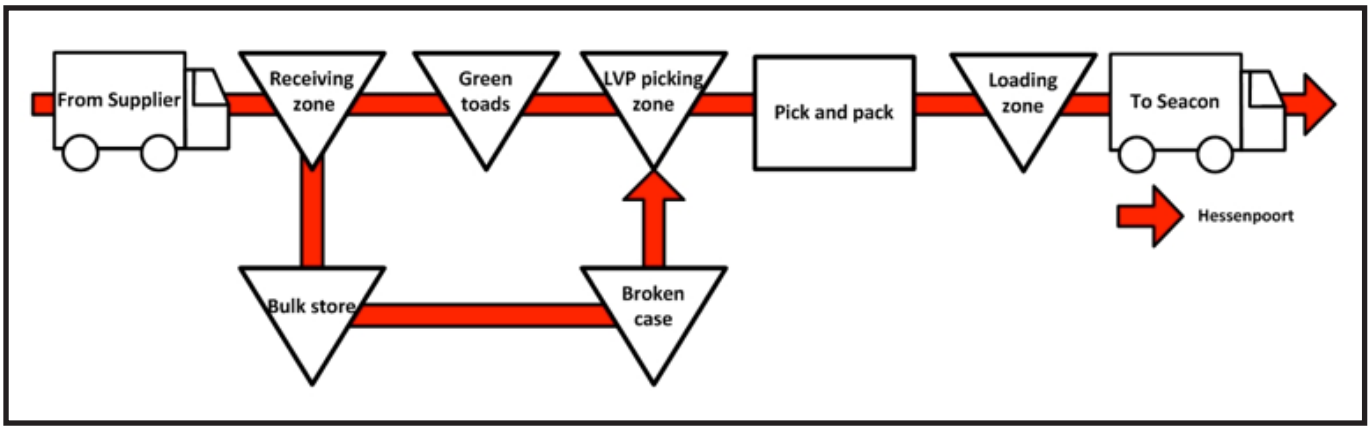


Figure 2.2 LVP processes

AUS- Average pick parts

AUS parts are of regular size and weigh less than 10 kg. Its reserve areas are the Pallet Reserve Area and the Box Reserve Area at Hessenpoort. Staphorst houses AUS Picking, which uses kanban. This separation of AUS picking is due to the historic growth of SLN. The author already notes this division between two locations seems illogical and causes extra costs. Chapter 3 further goes into this issue.

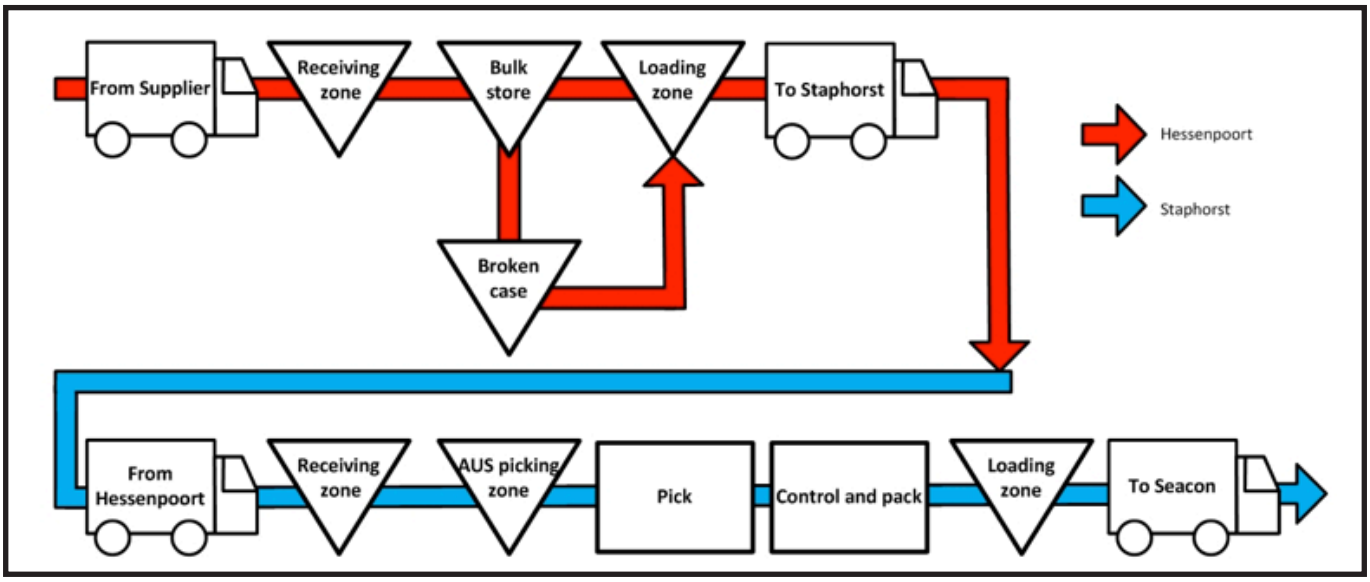


Figure 2.3 AUS processes

ASL- Heavy picking parts

ASL activities are situated at Hessenpoort. Employees pick ASL parts from an ASL Picking zone. This zone requests (using kanban) parts from the Pallet Reserve Area.

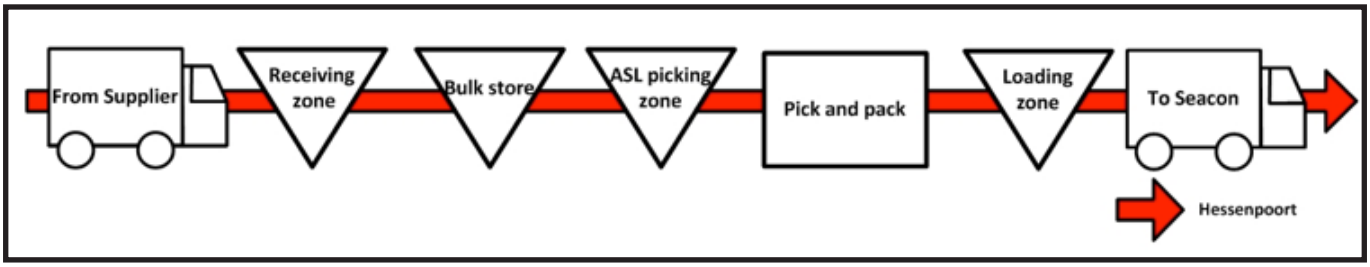


Figure 2.4 ASL processes

2.4.2 Dedicated processes

Unlike picking parts, dedicated parts are pre-assigned to a specific truck/batch. Again, External Sequence parts have external suppliers and Main Flow parts have internal suppliers. This section does not cover sub-assemblies, since SLN does not produce them.

External Sequence parts

Hessenpoort houses all External Sequence activities. Employees repack the parts to be sea worthy. Forklifts transport the parts via the receiving area to a floor location. Forklifts pick them up and bring them to the workstation. Employees handle the parts and bring them to the loading area, where they await transport to Seacon.

Main Flow parts

Staphorst houses all Main Flow activities. Upon arrival, parts are temporarily stored on the floor. Forklifts bring them to a gravity flow rack, pick them up again and bring them to the workstation. Employees pack the parts in seaworthy materials and Forklifts bring them to a loading area, where they await transport to Seacon.

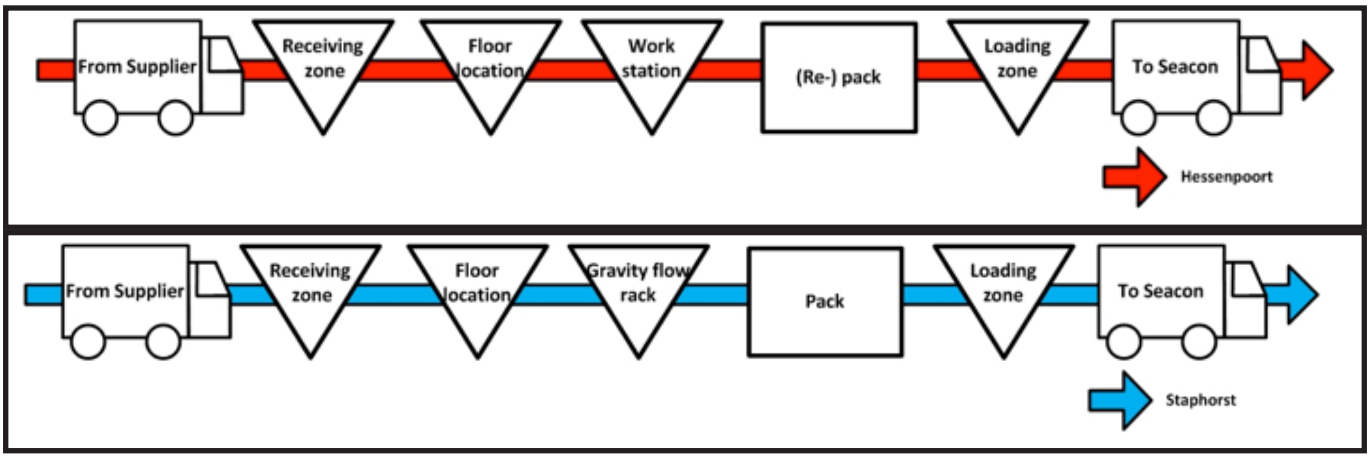


Figure 2.5 External Sequence processes (left) & Figure 2.6 Main Flow processes

2.4.6 Packaging

General truck production uses so-called greenwood packing materials, which Scania uses/reuses globally for several years. Scania Russia is the only KD customer with material return flows, so for other countries SLN uses cheaper non reusable packaging, called lightwood. Lightwood is supplied to and constructed at Staphorst, which supplies the other locations.

Upon Staphorst arrival, employees store the materials at various locations. Some locations are for usage at a workstation and some locations are used for temporary storage. Items for other locations are either shipped as materials or first build up. Sita, a supplier, build up packaging. Packaging for other locations is sent to Scania Production Zwolle and Staphorst.

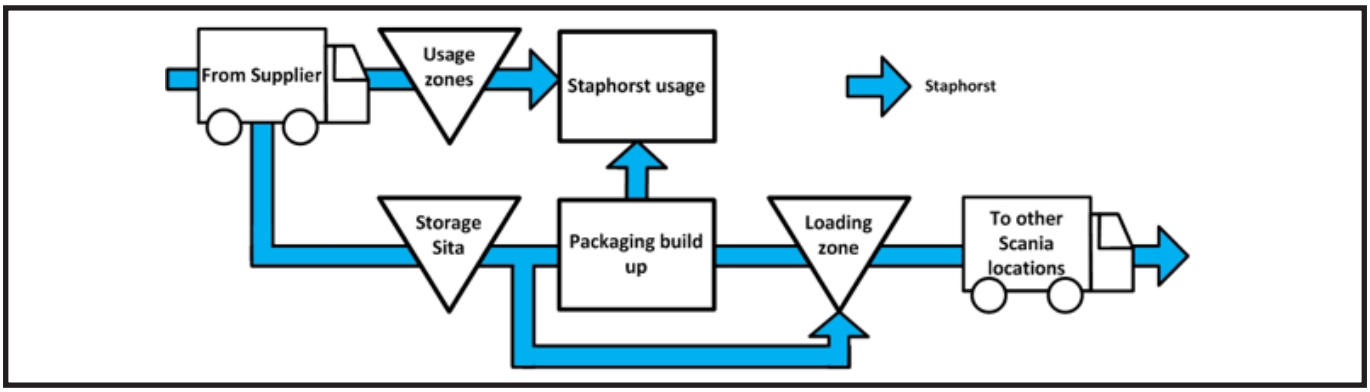


Figure 2.7 Packaging processes

2.5 Current layout Hessenpoort

Hessenpoort (Figure 2.8) in northern Zwolle, is the headquarter of SLN. It houses most offices and executes the following operations:

- Reserve storage for AUS, ASL and LVP
- Picking and packing of ASL and LVP
- External Sequence part processing

2.2.1 Receiving

Hall 2 receives order pick parts and Hall 4 External Sequence parts. Forklifts unload the trucks outside, try to sort the pallets and store them at the receiving zone. An employee labels the pallets to match their reserve area location and releases them for storage.

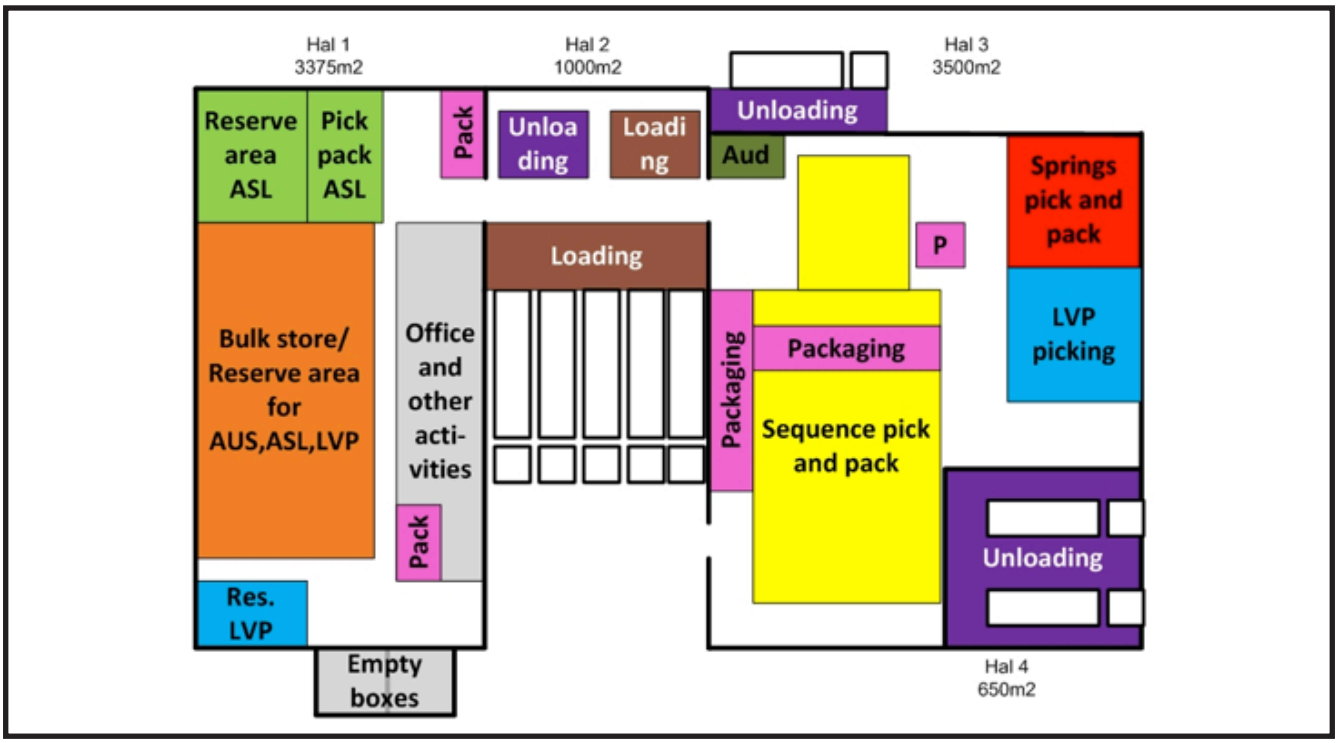


Figure 2.8 Layout Hessenpoort

2.5.2 Storage

Forklifts pick up the pallets at the receiving area and bring them to either the Pallet reserve area (All order pick parts) or the Box reserve area (LVP/AUS). The drivers retrieve the storage locations from the new labels, and place the pallets at the front of their destination aisles. Reach trucks pick up the pallets up and store them in their locations. Each reach truck covers a so-called function area of three aisles.

2.5.3 ASL picking and packing

The ASL packing station is located next to the ASL forward area in hall 1. At the station, employees pack the parts. Finally, forklifts picks up the pallets and bring them to the Seacon loading zone in hall 2.

2.5.4 LVP picking and packing

Hall 3 houses LVP Picking. Pickers first build up pallets for a batch and then take a pallet with them to pick its contents. Finished pallets go to a packing station within the area, where inspectors verify their contents and seal them.

2.5.5 AUS

Hall 1 houses both reserve areas. When Staphorst requests come in, a printer automatically prints relevant labels. Reach truck drivers pick up the labels for their zone, get the pallets from the storage, re-label them and put them in front of their aisles. Forklifts pick them and bring them to the loading zone.

2.5.6 External Sequence

Hall 3 houses the External Sequence station and Hall 4 houses the unloading area. Upon arrival, forklifts bring the pallets to a floor location besides the workstation and then to the workstation, where employees repack them. Forklifts pick up finished parts and bring them to Hall 2 to await shipping.

2.2.7 Springs

Springs are a special kind of External Sequence items and have a separate workstation in Hall 3. The Pallet Reserve Area replenishes this station. Forklifts bring springs for a certain period to the workstation. Employees pack them;

forklifts pick them up and store them in the loading area in Hall 2.

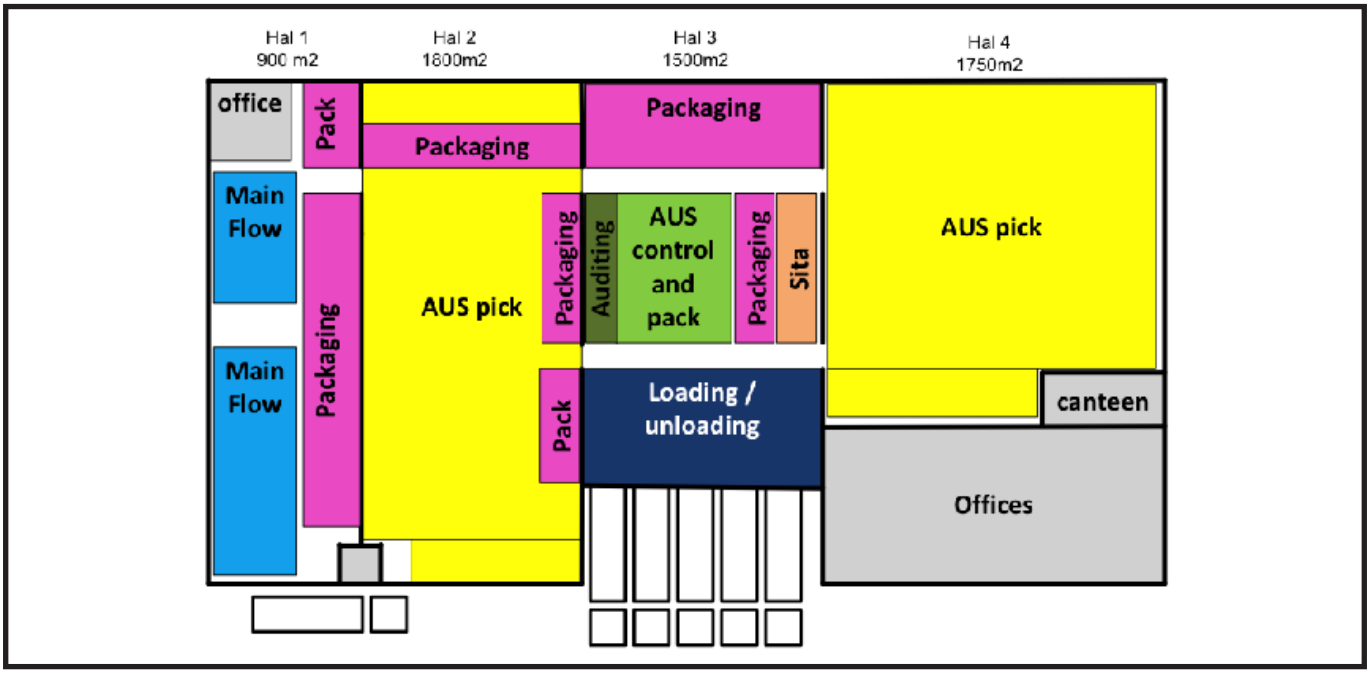


Figure 2.9 Current Layout Staphorst

2.5 Current Layout Staphorst

Staphorst (Figure 2.9) is the other SLN warehouse and houses the following activities:

- Picking and packing of AUS
- Processing of Main Flow parts
- Processing/build-up of lightwood packaging
- Label printing

2.5.1 Receiving & Storage

Staphorst has two receiving areas. One in Hall 1 and the other in Hall 3:

- Hall 1 receives Main Flow parts and packaging and lightwood packaging materials. Main Flow is put in the lower light blue part. Lightwood is in the packaging material storage at Hall 2.
- Hall 3 receives AUS parts and packaging materials other than lightwood. Trucks couple to the loading dock, so forklifts can ride in and out. They sort the pallets and put them in the unloading area (Figure 2.3). From there, forklifts bring the pallets to the picking stations.

2.5.2 AUS Picking and Packing

Halls 2 and 4 house AUS Picking, Hall 4 lighter parts and Hall 2 heavier parts. Order Pick Trucks take a pallet, pick its contents and store the filled pallet at a put away area next to Hall 3. Forklifts pick them up and place them on a roller conveyor in the Hall 3 packing-area. Packers verify the pallet´s contents and seal them. Forklifts pick the pallet up and place them at the loading/unloading area.

2.5.4 Main Flow

Hall 1 houses the Main Flow activities: work in progress in the lower area and a workstation in the upper area. A forklift brings the parts from work in progress to the workstation, where employees pack the parts in sea-worthy materials and put them in customer-specific order. A forklift picks them up again and brings them to the loading/unloading zone, where they await transport.

2.5.5 Packaging
Staphorst receives, partly builds up and distributes lightwood-packaging materials for KD. The material enters Staphorst at the Hall 1 unloading area and forklifts bring it to a packaging stock points in Hall 2 or Hall 3. In Hall 3, Sita, an external party, builds the packaging. Thereafter it is sent to the other locations.

2.5.6 Label and part-list printing
In the printing room, a small room between halls 1 and 2 employees print all labels and part-lists for end products, i.e. products that go to Seacon. Truck drivers, whom are already heading to other KD-facilities, take with them labels and part-list for their destination.

2.5.7 Auditing
Next to the AUS conveyors is one auditing conveyor. A forklift picks up an already finished pallet and puts it on the conveyor. An employee reopens the pallet and verifies if its contents match the prescriptions. Then, the auditing employee seals the pallet again and a forklift brings it back to the loading/unloading area.

2.5.8 Loading
Truck that pick up goods at Staphorst are attached to the loading docks at Hall 3. Forklifts pick up the relevant pallets and place them inside the truck. Exceptions are the Main Flow parts, which are picked up in the lower part of Hall 1.

2.6 The future of SLN

2.6.1 External Sequence will disappear
SLN deems External Sequencing waste and is working on letting suppliers pack sequence items in the required KD packaging. This means the External Sequence function will gradually disappear and capacity requirements will similarly decrease.

2.6.2 Full LVP units for Russia
Scania Russia makes 40% of the KD-demand. Because of this high demand, SLN mainly reduces handling for this market. SLN will send Russia bound LVP parts as much as possible in their original packaging. This reduces LVP Picking, transport from reserve areas to LVP Picking and required picking capacity.

2.6.3 Packaging project
SLN works on a packaging project. Currently, Staphorst receives and builds all lightwood materials and distributes them to the other locations. SLN is changing this to reduce handling and required capacity.

SLN has found a supplier whom can (1) manage its packaging materials and can deliver build-up MU's to the various processes and (2) handles the used up packaging materials (e.g. empty material units). This means packaging capacity can be used by other activities. SLN estimates it needs ca. 50 m²/location to facilitate supplier activities such as the build up and temporary storage. The project team has taken this 50 m2 in the Requests For Quotation towards potential suppliers.

2.6.4 NILE: Cross dock at Hessenpoort
The NILE Project means placing a cross dock at Hessenpoort. This cross-dock will process ca. 4 truckloads/day. Its customers are Scania Production Zwolle, Scania Logistics Netherlands and the paint shop in Meppel. Current estimations are the Nile project needs ca. 200 square metres.

2.6.6 Scania Production Zwolle boxes at Hessenpoort

Scania Production Zwolle will rebuild part of its warehouse and therefore needs to clear out capacity. It will therefore temporarily move its Box Reserve Area to Hessenpoort. The expected duration is between 1 and 1.5 years.

2.7 Chapter conclusion

This chapter describes Scania, SLN and the KD process. It answered the following question:

"Which activities does SLN perform and how are these activities organized?"

Sections 2.1 and 2.2 introduce SLN as the main KD Producer. Section 2.3 introduces Hessenpoort and Staphorst as SLN's facilities, introduces Scania Production Zwolle and the Meppel paint shop as internal suppliers and notes all facilities supply their goods to Seacon in Meppel, which brings the containers to their respective countries via the Port of Rotterdam.

Sections 2.4 and 2.5 describe SLN's processes and facility layouts. Hessenpoort contains bulk storages for AUS, LVP and ASL and pick stations for LVP and ASL and External Sequence. Staphorst contains pick stations for AUS and External Sequence and distribution of packaging materials. The main activities at both locations are receiving, storing, picking (and packing) and auditing.

Section 2.6 introduces future developments and projects that affect SLN. Disappointing demand and resulting overcapacity mainly drive these developments. Changes include possible decentralization of package building, shrinkage of the External Sequence function and new activities such as Cross docking or handling of Zwolle Boxes at Hessenpoort.

Chapter 3 gives a problem analysis. It introduces the number of material flows/transports, the inventory levels and unnecessary activities as main problem areas that affect layout related costs within SLN.

3. Problem analysis

Chapter 3 describes observed issues at SLN. It uses interviews, observations and data-analysis to find which factors affect the layout costs. A cause and effect matrix depicts/summarizes the relationships between issues and helps to clearly identify problems and causes (Heerkens, 2005). Chapter 3 answers research question 2:

"What are the main issues associated with SLN's current processes?"

3.1 Unnecessary processes: labelling, Control and External Sequencing activities

SLN executes various seemingly unnecessary processes: Labelling, control activities and External Sequence activities. They enlarge the dwelling time at the facilities. Higher dwelling times mea higher work in progress (Hopp & Spearman, 2008). Off course, higher work in progress means more capacity is required.

Labelling

The current KD process contains several labelling activities. E.g. a pallet of AUS parts:

- When Hessenpoort receives the pallet, it is labelled before put in the bulk store. Additionally, most pallets have to wait for an entire group of pallets to be released.
- The pallets can be relocated. In this case, it is relabelled.
- Upon a Staphorst request, the pallet gets a Staphorst label before being sent there.

Pallets receive a label several times, while pick locations are fixed and could be mentioned by an earlier label. Relabeling causes additional handling and potential mistakes; Part numbers can appear similar, while they sometimes differ only in one number.

Control activities AUS and LVP

After AUS or LVP Picking, employees check each pallet for containing the correct parts in the correct quantities and being undamaged. These 100% checks cause major handling. E.g. LVP control employees re-weigh most LVP parts to check them.

External Sequence activities

At the External Sequence station, employees repack parts and put them in the right order. Mostly, employees strip the old packaging and build new packaging around the part. In some cases, the new packaging only includes one piece of additional protection

3.2 Inventory

The observed inventory-level issue is twofold and present at both SLN facilities. (1) Many parts are in storage and (2) the amount of packaging material is large. High inventories require more storage capacity within a facility, which again influences the layout.

Many parts are in the reserve and picking areas. We identify three sub problems: ***(1) Obsolete parts***. When parts are needed, SLN orders them. In case of slow-movers, SLN does not trade off inventory costs vs. costs for procuring new parts. SLN recognizes the issue and executes projects to remove obsolete stock. ***(2) Pick areas use kanban with two or more pallets/boxes per part, regardless of its usage on that day.*** Scania knows several days in advance how many it needs of each part. E.g. some parts have 6 pallets in the pick area, while there may be no usage for several days. ***(3) Picking areas are not in the ERP-system.*** Picking areas request parts from the reserve area. When this happens, the ERP system sees no parts left and unjustly orders new parts (including parts for safety stock).

Packaging inventories are high. E.g. the External Sequence station, the ASL station and the Main Flow station have packaging material inventories. These inventories seem high. When asked about this, employees state high inventories are "to prevent out of stock". They are not configured to attain certain service levels and control costs.

3.3 Material flows

Material flows quantities seem higher than necessary. These quantities impact the effectiveness/efficiency of layouts. This issue can be divided in the system level, the facility level and the workstation level:

System level

There are two large internal material handling flows.

1. Hessenpoort houses the AUS reserve area, while Staphorst houses AUS Picking. Pallets required at Staphorst must be transported from Hessenpoort by truck.
2. Scania currently constructs lightwood packaging at Staphorst and from there transports it to other locations. This causes SLN to transport empty (sometimes build up) packaging.

Facility level

Between workstations flows are affected by the facility layouts. Several layout elements at both facilities seem illogical and increase travel distances. These elements include:

- Auditing stations do not have many flows going from/to them, but still have relatively central facility locations.
- Workstations have more/fewer capacity than seems apt. E.g. the spring station, the External Sequence and Main Flow areas, the sequence receiving area and the auditing areas.
- The distance between the reserve areas and LVP Picking is one of the largest within Hessenpoort. Still, the bulk store has to make frequent refills to the pick station.
- ASL packing is located in Hessenpoort Hall 1, which further only has storage space.
- Separation of Main Flow and External Sequence seems strange, because they are very similar activities. We expect combining them may reduce required capacity and travelling distances.

Workstation level

Within workstation flows seem higher than necessary, especially in storage/picking areas. Areas are not designed to support low travelling distances. E.g. slotting (which part has which location), routing and picking zones. SLN fills the Hessenpoort Pallet Reserve Area from the side opposite from the loading docks. This is contra-productive, because average travel distance to the storage is farther away than the station´s midpoint. SLN is working on this issue.

Two issues complicate flow-optimization within storage and pick areas.

1. The ERP system is rigid. Changing e.g. part slotting costs much handling and time.
2. SLN lacks picking behaviour management. Pickers determine their own routing and their behaviour is not monitored. Behaviour managenent is therefore hard and slotting/routing policies cannot be implemented.

3.4 Conclusion & Preview

Chapter 3 analyzes layout issues at SLN. Three categories structure these issues: “Material flows”, “unnecessary activities”, and “Inventory”, several causes for the issues exist. Chapter 4 continues this study by presenting a literature review. Scientific literature gives useful knowledge and tools that enable us to answer our sub questions and our main question.

Chapter 4 reviews literature that helps us solving our facility layout problem at SLN and based on this literature formulates this study’s solution approach.

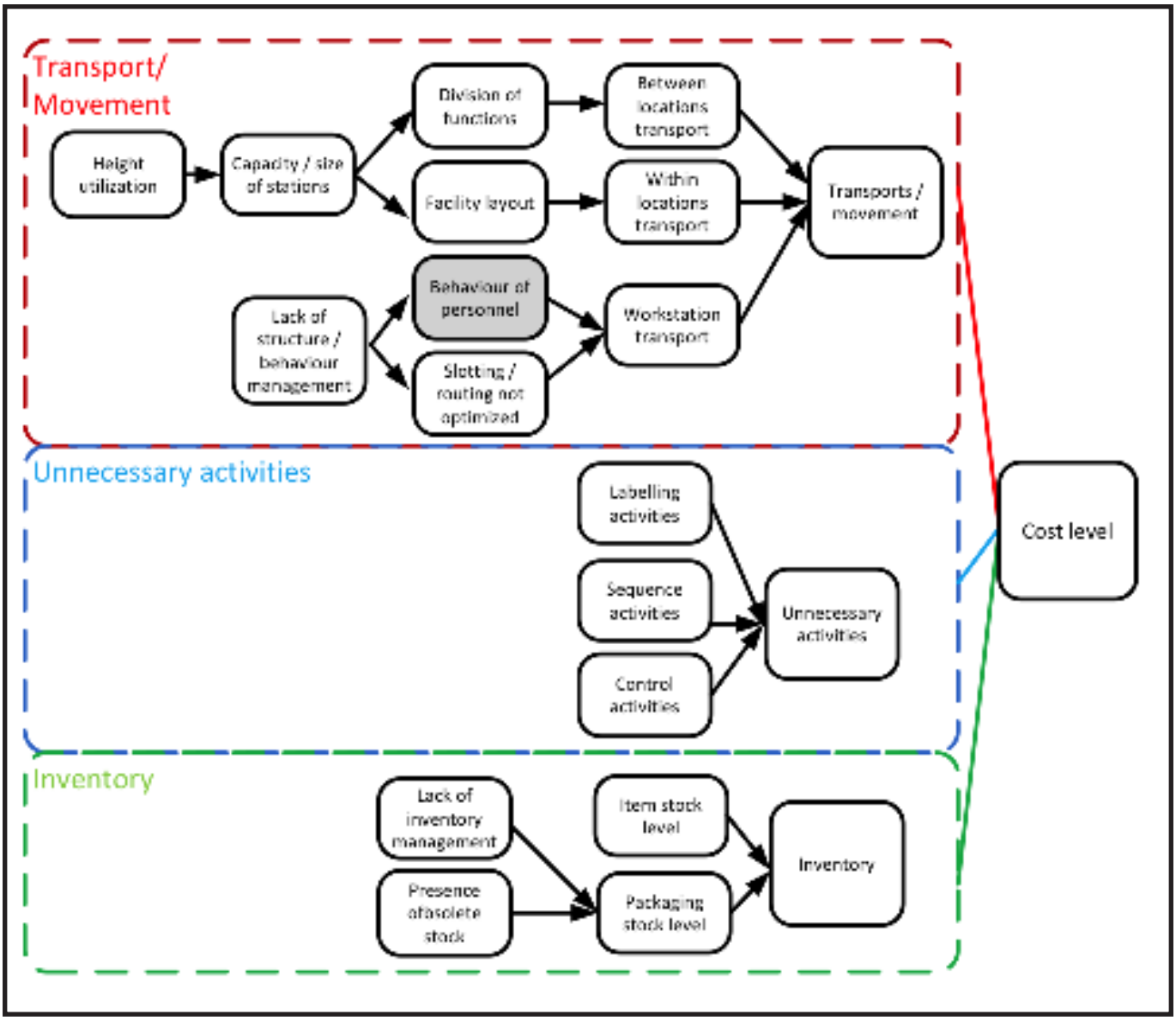


Figure 3.1 Cause & Effect matrix

4. Theoretical Framework

Chapter 4 forms a theoretical framework for our study and answers the question:

"Which scientific literature is needed to solve the facility layout problem at SLN?"

Section 4.1 explains uniform graph partitioning. Sections 4.2 and 4.3 introduce general facility and warehouse layout design. Section 4.4 introduces Muther's Systematic Layout Planning and Systematic Handling analysis procedures. Section 4.5 explains common method characteristics. Section 4.6 treats exact layout. Section 4.7 explains the use of specific and meta-heuristics. Section 4.8 explains capacity analysis Section 4.9 covers our procedure and Section 4.10 gives a chapter conclusion.

4.1 Uniform Graph Partitioning

Uniform Graph Partitioning divides a graph (set of nodes) in two partitions such that the sum of link weights between them is minimal (Hromkovi et al., 2007). It is mostly applied as a local search algorithm. The most popular heuristic is 2-opt in which one exchanges two nodes between the partitions. One can, however, also apply UGP as constructive heuristic in which one constructs a solution with no predefined allocation.

In case of two subsets, the set are mostly defined as V_1 and V_2, the objective function of UGP can then be defined as (Jayakumar & Reklaitis, 1993):

$$\sum_{i \in V_x} \sum_{j \notin V_x} c_{ij} \tag{4.1}$$

C_{ij} is the cost of linking nodes i and j. These costs only apply if i and j are in the different partitions. C_{ij} can have value 0 if not being in the same subset yields no costs.

Application at Scania: Uniform Graph Partitioning "light" suffices

Our facility layout problem is special, since it contains two locations. Uniform Graph Partitioning can help solve the problem at the facility level, where we want to minimize the between facilities distances. If this top level is fixed, two separate optimization functions remain. Related functions such as reserve areas and order pick areas (Where the first supplies the latter) have costs associated with being in separate subsets i.e. facilities.

Since the problem is delimited and is easy to solve by hand, we apply a simpler algorithm instead of traditional Uniform Graph Partitioning. We use the method's logic such that we allocate departments to minimize between-facilities distances. Because of our case's low complexity, we do this by hand.

4.2 Facility layout and flows

Meller & Gau (1996, p. 153) define the facility layout problem as:

"The facility layout problem is concerned with finding the most efficient arrangement of m indivisible departments with unequal area requirements within a facility."

In facility layout, efficiency means a low amount of material movements (Singh & Sharma, 2005). Sing & Sharma note reductions in material movement have additional positive effects on work-in-process, throughput times, product damage, facility congestion and material scheduling and control.

Manufacturers face increasing uncertainty towards internal forces, such as production breakdowns and external forces, such as market demand (Kulturel-Konak, 2007). To be competitive and cope with such uncertainties firms need to adapt robust layouts.

The facility layout problem can be divided in:

1. ***The block layout problem*** determines the size, shape and location of departments. It mainly affects macro flows within the facility (Tompkins et al., 2010; Meller & Gau, 1996). It is a complex problem, for which distinctive optimization- and heuristic methods exist.
2. ***The detailed layout problem*** determines the within-department placement of resources. It is more delimited than the block layout problem, since factors such as department boundaries and floor constraints are fixed (Muther & Haganäs, 1969). Muther & Haganäs advice to plan not each area in detail, but to plan areas as far as necessary.

4.2.1 Scania

Literature shows we can structure our problem definition by dividing the problem in (1) a block layout and (2) detailed layout. The main goal of such layout optimization is to minimise the travelling distances between and within locations. Our solutions need to be robust with respect toward e.g. market uncertainty.

4.3 Warehouse flows and layout

Similar to general problems, warehouse layout problems have two sub problems (de Koster et al., 2007), viz., placing the departments and within-department planning. De Koster et al. state general facility design methods apply to warehouses. We address these methods in this chapter.

4.3.1 Warehouse function and flows

Heragu et al. (2006) distinguish four types of warehouse flows (Figure 4.1):

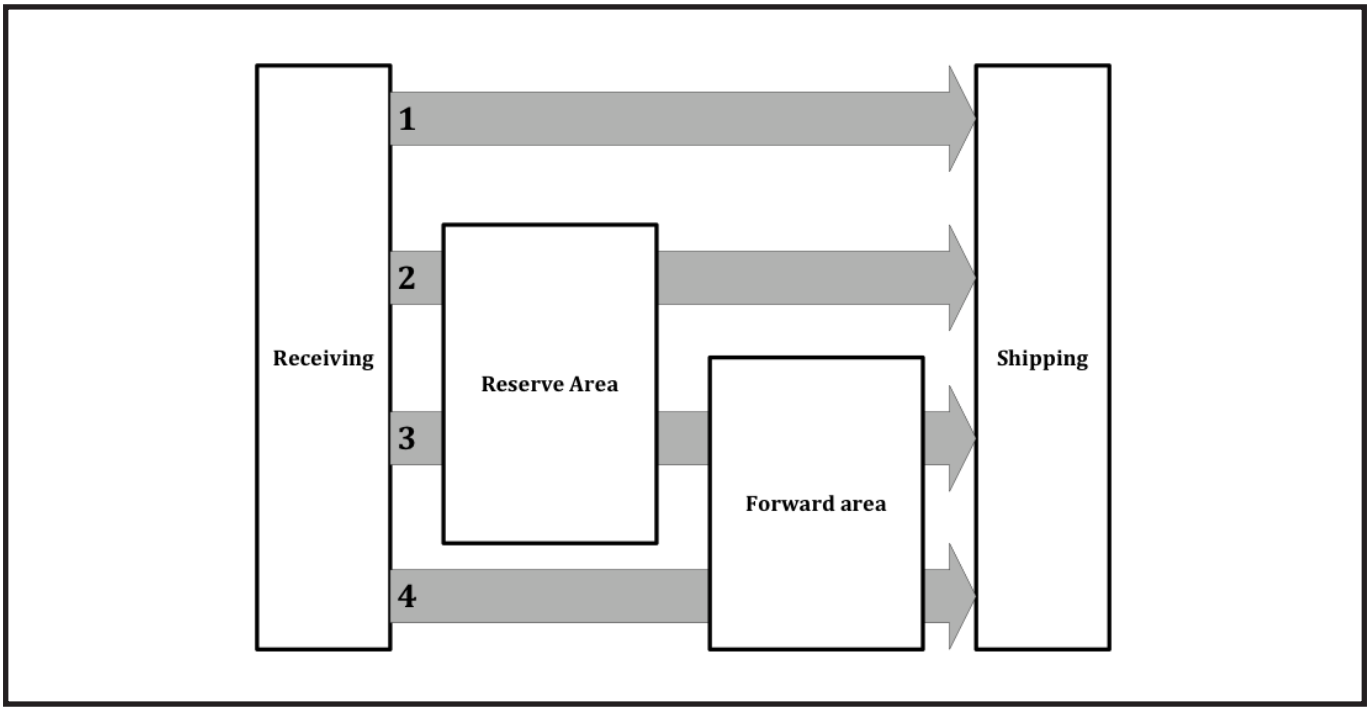


Figure 4.1 Typical warehouse flows (Heragu et al., 2006)

1. Cross docking: Parts go directly from receiving to shipping.
2. Parts only visit a reserve area. Employees pick in this area. Heragu et al. assume this stream mainly applies to slow-movers.
3. Parts first visit a reserve area and then a forward area. In this forward area, employees perform picking and other value adding activities.

4. Parts skip reserve areas and directly visit a forward area. This flow type facilitates consolidation of orders. Heragu et al. regard (4) as a type of cross docking.

Heragu et al. further develop a mathematical model, which assigns, given inventory costs and capacity, each part to a flow. This is not applicable to our situation, given that at SLN, a part is not strictly assigned to one flow type.

4.3.2 Layout and management of storage/pick areas

Several strategic and tactical decisions influence handling within storage and pick areas. Scholars mention several of these decisions. These decisions do not stand alone, but also affect each other (Bartholdi & Hackman, 2010):

Aisle & Storage structure: One can configure the aisle structure to support low travel distances. The width, quantity and placement of aisles are important factors. E.g. wide aisles improve accessibility, but increase required floor capacity and travelling distances.

A Storage policy defines which part to place where in the storage. Generally, fast-movers have closer locations than slow-movers (Bartholdi & Hackman, 2010). Several storage policies exist (Heragu, 2006):

1. ***Random Storage-*** SKU's are assigned to random free warehouse locations.
2. ***Dedicated Storage-*** SKU's are stored at predetermined locations
3. ***Class based storage-*** SKU's are semi-randomly stored in zones, based on the SKU being a fast mover or slow mover (or in-between).

The forward/reserve problem Most warehouses have forward and reserve areas (Heragu et al., 2006). Reserve areas replenish the forward areas. The forward-reserve problem determines which parts to store at which area at what quantity (Roodbergen, 2001).

Picking routes Batching is mainly applied in case of order picking. In this case it is worthwhile to optimize picking routes, i.e. dividing a set of orders between batches. No method gives good solutions in little time for all warehouse instances (Bartholdi & Hackman, 2010), routing needs to be optimized individually, in conjunction with factors such as aisle-/storage structure and storage policy.

Storage/retrieval equipment Several technological solutions make warehousing more efficient (Bartholdi & Hackman, 2010; Heragu, 2006). E.g., special racks, conveyor systems and AS/RS systems. Efficiency can improve in terms of (1) Throughput (parts/hour) and (2) Capacity utilization, because of higher stocking and smaller aisles

4.3.3 Scania

This section states the mathematical model of Heragu et al. does not apply to our situation. We can however use their flow division to analyse current flows. It teaches us choosing different flow types can reduce the number of workstations visited, thus lowering total transportation costs.

4.4 Systematic Layout Planning & Systematic Handling Analysis

Richard Muther is the most famous author in the field of facility layout design. He developed several layout-/ materials handling planning methods. Some still form the basis for current research in their fields. Two methods are important to this study.

One is Systematic Layout Planning (SLP) (Muther, 1968) and the other is Systematic Handling analysis (SHA) (Muther & Haganäs, 1969). Both consist of a series of steps one follows to (re-) design a layout or handling system.

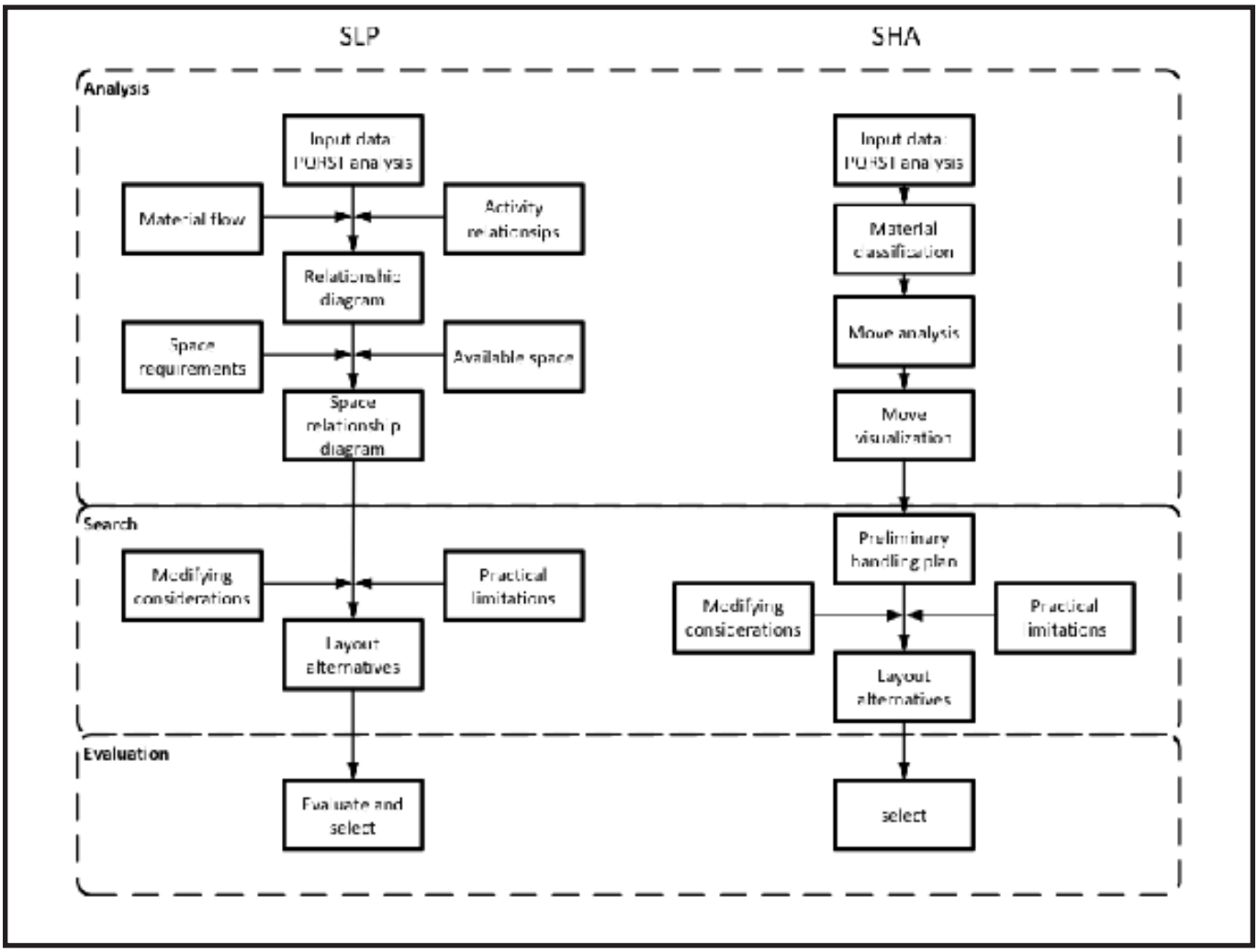


Figure 4.2 SLP (Muther, 1968) and SHA (Muther & Haganas)

4.4.1 Systematic Layout Planning

Muther (1968) divides Systematic Layout Planning (Figure 4.3) in four phases:

1. Location — Which area is to be used for facility planning?
2. General overall layout — Construction of departmental arrangement/block layout.
3. Detailed layout — Placement of resources within departments/blocks.
4. Installation — Planning and execution of physical placement.

According to Muther, the facility planner mainly deals with steps (2) and (3). He/she makes sure step (1) is agreed on and the final layout is approved to perform step (4). Muther developed a procedure that the planner can apply in steps (2) and (3). It consists of three phases: Analysis, Search and Selection (Tompkins et al, 2010). Analysis identifies the required activities, their capacity requirements and in-between material flows. The first step is a PQRST analysis:

- Which products does the facility handle? ***(Product)***
- How much of these products does the facility handle? ***(Quantity)***
- What series of steps does each product go through? ***(Routing)***
- Which extra activities do the processes require? ***(Supporting services)***
- When and how long do processes have to executed? ***(Time)***

Given this analysis, the planner composes a Relationship Diagram, i.e. a node and arc structure to depict inter-departmental flows. Generally, arc-thickness represents the flow quantities. Subsequently, the planners computes the activities' capacity requirements of, which he/she adds to convert the relationship diagram to a Space Relationship Diagram, which has squares instead of nodes to represent departments. Generally, square sizes represent capacity-requirements.

In the Search phase, one trades off modification alternatives and layout restrictions (e.g. shape of a building) to come up with layout alternatives. In the selection phase, one evaluates these alternatives to find a definitive layout.

4.4.2 SHA

Muther & Haganäs (1968) define the goal of SHA as to design and implement facility/department handling plans, which define the way of moving materials between/within departments. Muther & Haganäs (1968) divide SHA in four phases:

1.	External integration	Consider which flows go from/to the total facility
2.	Overall handling plan	Construction of the overall facility handling
3.	Detailed handling plans	Construction of handling per individual department
4.	Installation	Planning and execution of the handling plan

Similar to SLP, the planner mainly deals with phases (2) and (3) and must again assure agreement on external integration and on agreement before installation. Again, a PQRST analysis is the first Analysis step. The next steps are material classification and movement analysis. Material classification means the planner groups materials based on attributes that determine its transportability. Muther & Haganäs identify four types of characteristics:

1.	Physical characteristics	E.g. weight, size and shape.
2.	Quantity	How many items will be moved from where to where?
3.	Timing	E.g. urgency and seasonal effects.
4.	Special control	The company or government enforces limitations and regulations to material handling.

Based upon this classification and the facility layout, the planner analyses material moves, i.e. part-routing and flow intensities. The planner can apply tools such as the aforementioned relationship diagram to visualise these moves.

The search phase starts with several preliminary/rough handling plans, whose details are to be determined. The planner uses them to elaborate modification considerations (taking restrictions into account). The planner defines modifications and calculates their effects. This defines the resulting alternatives. The last step is to evaluate the alternatives and to choose a handling plan.

4.5 Approach classification

Several exact and heuristic approaches exist to solve facility layout problems. They differ amongst each others in several factors. This section covers these distinctive features.

4.5.1 Exact procedures versus heuristics

Facility layout techniques can be divided in exact and heuristic procedures (Marcoux et al., 2005). Exact procedures provide optimal solution, but mostly cannot solve real problems in reasonable time. Heuristics solve this. Rather than finding optimal solutions, they search local optima/acceptable solutions in a reasonable amount of time (Michiels et al, 2007). Constructive and improvement heuristics exist. The former use a procedure to build up a feasible solution. Improvement/local search heuristics take an existing solution and based on that search for potential improvements. We choose to apply heuristics, because we have to be able to solve our problem in a reasonable amount of time.

4.5.2 Performance measurement: adjacency versus distance objectives

Generally, two objective functions exist to measure layout quality (Heragu, 2006). One is distance based (Equation 4.2), the other is adjacency based (Equation 4.3). Where f_{ij} is the quantity of flows between departments i/j. c_{ij} is the costs per unit of distance i/j, d_{ij} is the distance between i and j. x_{ij} is 1 if i and j are located next to (adjacent to) each other and 0 otherwise.

$$min \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} c_{ij} d_{ij} \tag{4.2}$$

$$min \sum_{i=1}^{m} \sum_{j=1}^{m} f_{ij} x_{ij} \tag{4.3}$$

The distance-based objective minimises costs for all inter-department flows. The adjacency-based objective maximises the number of flows going to neighbour-departments. This is based upon the idea that departments with high in-between flow quantities should be next to each other. We apply the distance objective (4.1) because it directly represents the total relevant cost of travelling from the locations to each other.

4.5.3 Discrete versus continuous representation

Facility layout models are either discrete or continuous. ***Discrete models*** divide facilities in a set of equally sized areas/grids (Tompkins et al, 2010). A department is assigned one or several grids. Smaller grids provide higher flexibility in departmental shapes and a more detailed solution, but also increase computation time. ***Continuous*** models are not bound to a grid structure. They are more flexible in departmental size. On the downside, they generally cannot deal with nonrectangular facilities/departmental shapes. Also, computer implementation of the continuous models is harder.

We apply a discrete representation. In chapter 1 we defined as one of our goals to deliver a facility layout tool. Computer implementation of discrete representations is considerably easier

4.5.4 Static versus dynamic problems

Facility layout problems are either static or dynamic (Drira et al., 2007). Traditionally, they were always static (Meng et al, 2004). ***Static*** models consider the product mix for one period. ***Dynamic*** models consider the effects of the product mix in several periods, to come up with long-term solutions. We apply a dynamic structure. We do not wish to optimise for only one timeframe, but rather for a series of time frames to get a good idea of averages and developments. This furthermore allows us to get better estimates for the amount of required capacity over time.

4.5.5 Robust methods

Most methods assume given demand over time (Drira et al., 2007; Marcoux et al., 2005). ***Robust methods*** (e.g. Montreuil & Laforge, 1992) however consider various demand scenarios to compute more robust configurations that are better able to withstand changes in demand and product mix. We apply robustness to our methods. This means we want to know the number of flows and required capacities for various amount of total demand per day. This allows SLN to see effects of their action, given various demand developments.

4.6 Exact facility layout procedures

Several exact procedures exist for the facility layout problem. We will only shortly cover these methods, because we already decided (Section 4.4) to apply heuristics. Exact methods aim at layout optimization. Scholars roughly divide exact approaches in three categories (Singh & Sharma, 2005; Meller & Gau, 1996; Tompkins et al, 2010):

Quadratic Assignment Problems Distance based Instances of the facility layout planning that link departments to distinct facility locations (Meller & Gau, 1996).

Graph theory Uses the adjacency maximization function (Meller & Gau, 1996). It uses departmental relationships to create adjacency graphs, which show which departments are 'neighbours' and uses its information to construct a block layout.

Mixed Integer Programming (MIP) approaches Continuous layout problem with rectangular departments (Tompkins et al, 2010). Most models (e.g. Montreuil (1991)) take department boundaries as decision variables and aim at minimizing Manhattan distances.

4.7 Facility layout heuristics

Over the years, many facility layout heuristics were developed. They do not optimise, but elevate the time insolvability problem of exact procedures, while obtaining satisfying solutions (Michiels et al., 2007). The following subsections introduce three well-known facility layout heuristics and meta heuristics that can help us solve our problem.

4.7.1 Specific heuristics

LOGIC- A slicing tree search procedure

Adjacency/distance based	Distance Based
Discrete / continuous	Continuous representation
Static / dynamic	Static
Robust	Not robust
Advantages	Structured way of representing a layout
Disadvantages	Tendency to come up with long, narrow departments Cannot cope with non rectangular departments or facilities

Table 4.1 LOGIC charactaristics

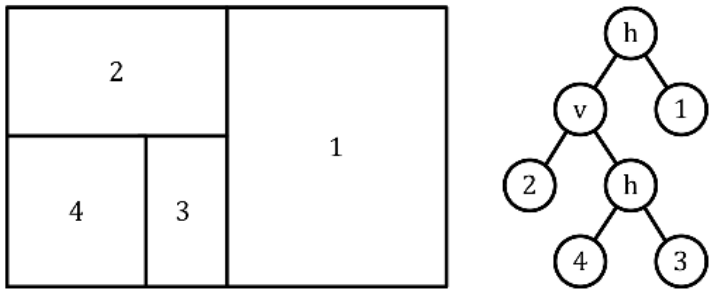


Figure 4.3 An example of LOGIC

LOGIC (Tam, 1992) is an improvement algorithm based upon a slicing tree representation (Meller & Gau, 1996). Slicing trees have several forms; the tree in Figure 4.4 has a horizontal/vertical structure. The upper (h) means the facility is horizontally divided. The right part only contains department 1. The left part is vertically (v) divided. Department 2 is located in the upper part. Departments 4 and 3 are located in the lower part is horizontally divided between 4 and 3.

LOGIC improves on starting solutions by applying Simulated Annealing to the tree parameters. E.g., Horizontal

becomes vertical or numbers are switched. An issue is that LOGIC is often results in long, narrow department shapes, which in practice can be infeasible. To solve this, the facility planner can constraint departmental height/ width ratios.

CRAFT- Department exchange procedure

Adjacency/distance based	Distance based- departmental centroids
Discrete / continuous	Discrete- department centroids
Static / dynamic	Static
Robust	Not robust
Advantages	Easy to apply Can cope with non rectangular departments and facilities
Disadvantages	Output needs reconsideration Gets easily stuck in local optima Can only exchange adjacent or equally sized department

Table 4.1 CRAFT charactaristics

CRAFT (Armour & Buffa, 1963) is a distance based improvement algorithm (Meller & Gau, 1996). Given an existing layout, CRAFT considers all possible 2/3 departments swaps and calculates their goal function values. If any swap is feasible and reduces distances, it executes the best swap. The algorithms stops when no swap yields an improvement.

CRAFT is easy to apply and can cope with irregular department shapes, thus giving a relatively realistic layout representation, but it has some disadvantages (Tompkins et al., 2010). Firstly, due to its shape flexibility, CRAFT can give strange department shapes, which the planner needs to be reconsider. Secondly, CRAFT always chooses the current best exchange option and easily gets stuck in a local optima (Meller & Gau, 1996). Thirdly, CRAFT can only exchange adjacent or equally sized departments, because otherwise 2/3 opt is not possible without shifting other departments.

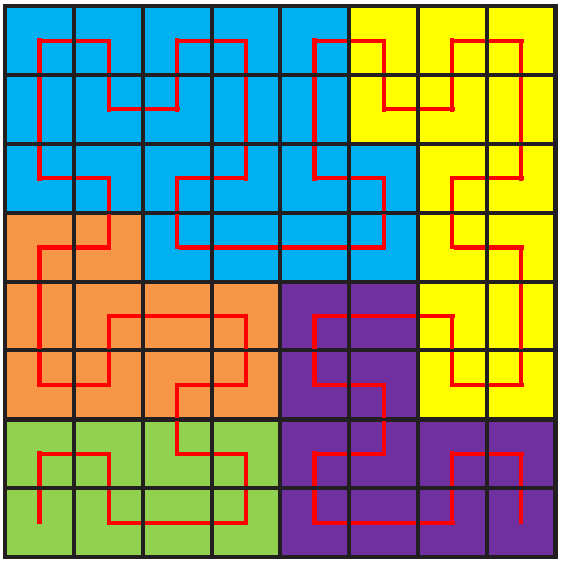
MULTIPLE- Departmental planning using space filling curves

Adjacency/distance based	Distance based- departmental centroids
Discrete / continuous	Discrete representation
Static / dynamic	Static
Robust	Not robust
Advantages	Flexible with non-rectangular facility shapes. Can exchange any two departments easily. Can cope with multifloor facilities
Disadvantages	Output needs reconsideration

Table 4.1 MULTIPLE charactaristics

MULTIPLE (Bozer, Meller, Erlebacher, 1994) is a constructive/improvement algorithm that uses space filling curves. MULTIPLE uses a grid structure. Space Filling Curves are lines, which visit each grid within a facility exactly once via distinct routings. Figure 4.4 exemplifies a Space Filling Curve.

Inputs are a sequence of activities and a Space Filling Curve. Though Space Filling Curves have a formal definition, the facility planner can draw his own curve. Most curves that theoretically are not space filling curves still work well for facility layout construction and improvement.



dpt.	cap
a:	20
b:	10
c:	14
d:	12
e:	8

Figure 4.4 Example of MULTIPLE with sequence e-b-a-c-d

MULTIPLE 'travels' trough the facility via the curve and assigns departments to the grids. I.e., given the sequence, the algorithm assigns grids to the first department, until it has enough grids. Department 2 gets the subsequent grids, etc.

E.g., in a 64 grid-warehouse, we want to assign five departments, which need 20, 10, 14, 12 and 8 grids of space. The input-sequence is e-b-a-c-d and we start left-under. The algorithm follows the curve and keeps assigning grids to department (e) until it has 8 grids. Subsequently, it assigns grids to departments (b), (a), (c) and finally (d). Figure 4.6 depicts the resulting layout. Similar to CRAFT, MULTIPLE performs pair wise department exchanges to improve the goal function. It simply changes the sequence in which departments are added to get a new solution.

Advantages are that MULTIPLY can easily exchange all department, independent of size/adjacency and can capture facility-shapes with high flexibility (Tompkins et al, 2010). It however cannot model department shapes in a prescribed way. Therefore the planner mostly needs to reconsider/adapt MULTIPLE solutions before they are feasible.

4.7.2 General- and meta-heuristics

In addition to specific facility layout heuristics, one can also use general heuristics to solve facility layout problems (Singh & Sharma, 2005). Local search algorithms try to improve on existing solutions by creating neighbour solutions (Michiels et al., 2007). These are solutions deriving from the starting solution. If the algorithm finds a better neighbour, it becomes the new starting solution. Most local search algorithms terminate when no improvement is available.

Local search methods can find local optima relatively fast, but few local optima are near a system optimum (Michiels et al., 2007). Meta-heuristics are more complex local search algorithms that solve this. They avoid getting stuck by sometimes accepting non-improving neighbours. Doing so, they can enter more favourable areas of the problem space.

Meta-heuristics are widely applicable and are used in various optimization fields, e.g. Vehicle Routing Problems (Cordeaux et al., 2001; Osman, 1993), Job Shop Scheduling (Van Laarhoven et al., 1992) and Maintenance Management (Lapa et al.,2000). Three meta-heuristics are commonly used for facility layout: Simulated Annealing, Genetic Algorithms and Tabu Search (Singh & Sharma, 2006).

4.7.3 Scania
Of the proposed heuristics, Logic is not suited for our problem. Both Hessenpoort and Staphorst are non-rectangular facilities and we already mentioned that LOGIC cannot cope with that.

4.8 Capacity management
Section 4.7 deals with capacity management, which is a basic SLP step. Subsection 4.7.1 describes general workstation capacity requirements. Subsection 4.7.2 describes the converting method, equipment & product mix analysis and Little's law as analysis tools.

4.8.1 General workstation requirements
According to Tompkins et al. (2010) each workstation needs capacity for:

- Equipment
- Materials
- Personnel

Equipment needs capacity for placement, travel and maintenance. Material needs capacity for temporary storage, in-/outbound shipping and waste disposal, temporary work in progress storage and holding of tooling and maintenance materials. Personnel needs capacity to work, handle materials and go in/out the station.

4.8.2 Capacity analysis tools

The Converting method (Muther, 1967) converts current workstation capacities to future needs. It is a logical and practical way to determine capacity fast. A downside of this method is that the facility planner will always be biased, because he/she takes current capacities as basis.

Equipment/product mix analysis (Heragu, 2006): Heragu (2006) proposes performing product and equipment analysis to find the required capacity for each workstation. These factors influence required capacity in the following ways:

> ***Used equipment*** Heragu uses storage areas as example. Used material handling devices and the type of storage racks affect required capacity.
>
> ***Product mix*** In a storage area, product types, sales volume and demand patterns of parts determine the required amount of storage capacity.

To perform a product analysis, facility planners can use product information such as bills of materials. This method is strongly linked with the PQRST analysis as mentioned by Muther (1968). Both methods weigh the influence of required facility/departmental contents.

Little's Law
Little's Law is a basic rule of factory dynamics and is defined by the following function (Hopp & Spearman, 2008):

Sojourn time=(Work in Progress)/(Throughput)

Hopp & Spearman note that Little's law implies that Sojourn Time and Work in Progress are directly linked. Using Little's Law, the facility planner can model the factory as queuing system (Bartholdi & Hackman, 2010).

4.9 Our Procedure
This section describes our procedure. We already noted that SLP was created in a time were no computer aid was available to facility planners. Current possibilities allow us to apply some more sophisticated methods. Still we want

to benefit from the structure that both methods provide. We mainly apply SLP in the analysis phase, to make sure we acquire required information.

4.9.1 Analysis

Recall the analysis phase of SLP means acquiring capacity and flow data to create a Space Relationship Diagram (Muther, 1968).

To estimate order pick flows and capacity requirements, we apply an order pick simulation. The model simulates demand in various periods/days and gives the averages and distributions of flow-quantities and capacity requirements.

We will calculate flows and capacity requirements of dedicated processes by hand, since these processes are more delimited in the number of parts.

4.9.2 Search and evaluation

The SLP analysis phase means searching layout alternatives. The evaluation phase means measuring the effectiveness of the alternatives and choosing the most favourable. We take both together: We simultaneously search for new solutions and directly measure their goal function values. This enables us to divide the problem in the i)system level and ii) facility level and b) to apply heuristic methods as described in this chapter.

In the search and evaluation phase, we incorporate the following approach:

1. ***System level***
   We begin our layout generating at system level and apply graph partitioning to determine an efficient between locations distribution of activities in terms of between location travel times.

   A transport analysis, which division of functions minimises transport?

2. ***Facility level***
   Given the distribution of activities, we create a layout per facility. To generate layout alternatives. We follow the following steps:

   Perform a combination of MULTIPLE and simulated annealing.. It can evaluate many layout alternatives in a fast and flexible way. Where original Multiple would only accept improving solutions, we accept non-improving solution with certain probabilities. The advantage of this approach is that we avoid getting stuck at local optima and can search for global optima, given the step 1 division of functions between Staphorst and Hessenpoort.

   We use MULTIPLE output as input for CRAFT. First we “fix” the MULTIPLE output options to become feasible. Subsequently, we search feasible exchanges to find good layout alternatives.

4.9 Conclusion & Preview

This chapter provides literature that can help us solving the facility layout problem. The first two sections described the facility and warehouse layout problem. Section 4.3 defined factors that influence efficiency of storage areas.

Section 4.4 introduces SLP and SHA as basic facility layout and handling analysis methods. They were created in a time were no computer aid was available, but still serve as basis for many layout methods. This is mainly because they offer the facility planner a structured way of working.

Sections 4.4-4.6 introduce several methods for the facility layout problem. Section 4.4 started by defining various

variables in which methods differ. Section 4.5 explained exact methods and Section 4.6 explained several heuristics. Section 4.7 explained various ways of capacity management.

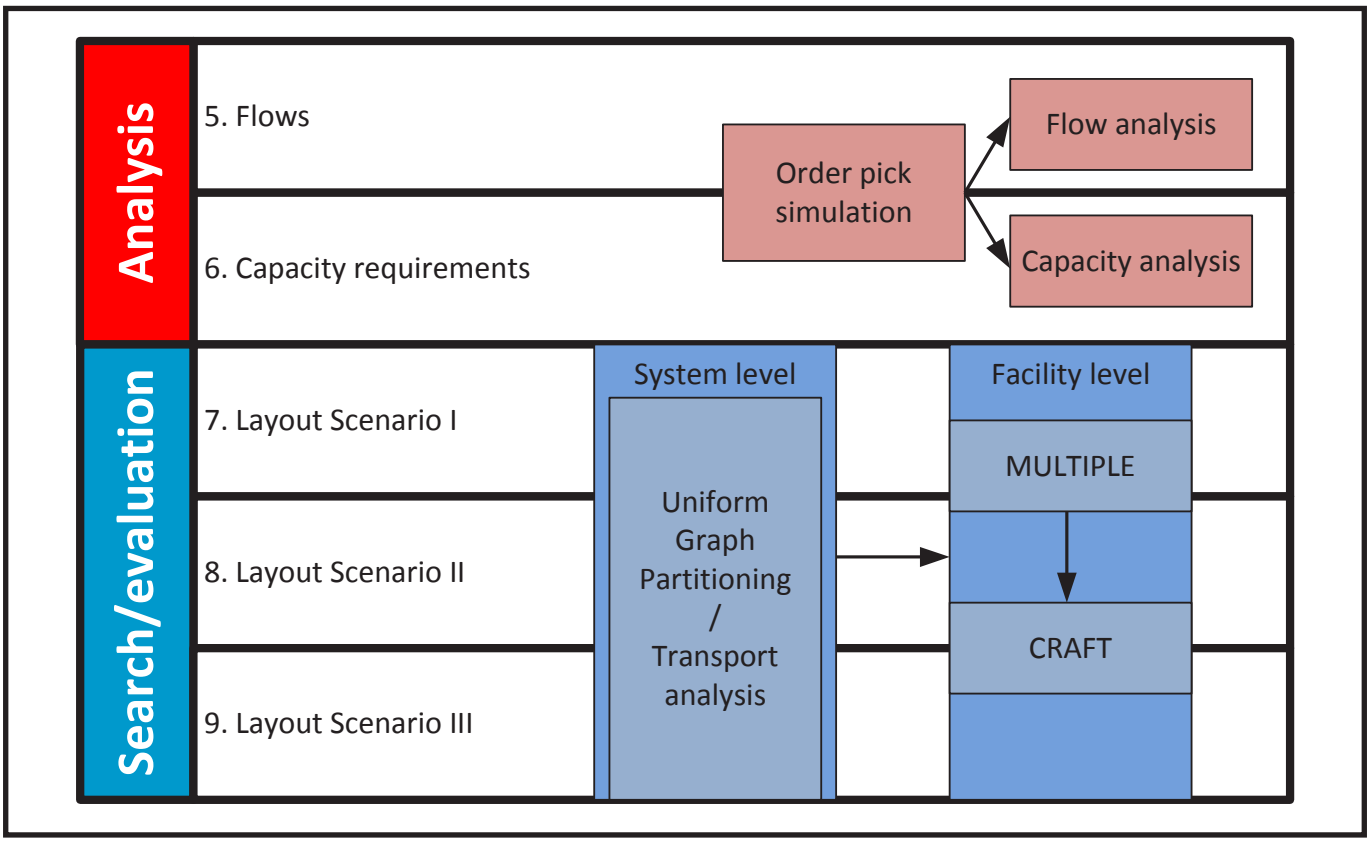


Figure 4.5 Method overview

5. System flows & redesign

Recall the SLP phases are Analysis, Search and Evaluation. During analysis one maps all relevant activities, material flows between and how much capacity the activities require. Chapter 5 analyses flows and activities to create a relationship diagram and thus answers Research Question 4:

"Which activities will SLN execute and which material flows will they create?"

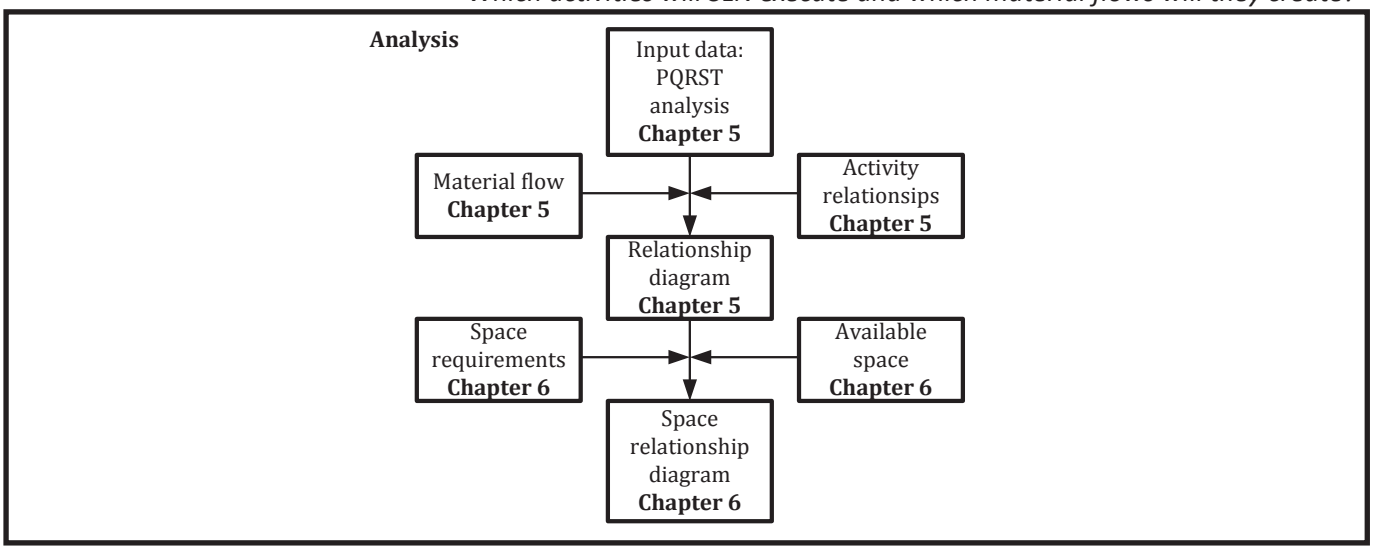


Figure 5.1 SLP analysis phase

SLN expected current demand to be 48/day and build its warehouses to facilitate that. Therefore, we set capacity for that takt. Current daily demand, however, is 18 to 24, which is at most half of what SLN expected and SLN currently does not expect demand to rise to 48 soon. Since management deems 36 trucks/day realistic on middle term, we agreed with them to take 36 trucks/day to calculate flows.

Section 5.1 proposes a redesign to the order pick processes. Section 5.2 introduces the used order pick simulation, which is central in calculating order pick flows. Sections 5.3-5.5 discuss material flows for order pick parts, dedicated parts, Zwolle Boxes and packaging.

5.1 Required activities

Chapter 2 mentions the following functions to be performed by SLN:

Orderpick parts	Dedicated parts	Other
Combined reserve area	Main Flow Handling	Zwolle Boxes
LVP Picking	External Sequence parts handling	Cross dock function
AUS Picking		
ASL Picking		
Springs Picking		

Table 5.1 Required SLN activities

We do not reserve separate Cross docking capacity. Instead we reserve extra capacity for Receiving/Send areas. SLN estimates required capacity at five trucks. Chapter 6 further analyses this.

5.2 Order pick process redesign

Chapter 3 notes KD order pick processes add little value, hence we propose a system redesign. Heragu et al. (2006) distinguishes four order pick streams. Currently, all parts visit a reserve and a forward area. Heragu et al. mention three alternatives to shorten material flows:

1. To skip the reserve area
2. To skip the forward area
3. To skip both the forward and the reserve area (Cross-docking)

Scania requires parts to arrive at least two days before usage. It is hard to skip reserve areas, since Scania dictates parts to be stored there. This eliminates options (1) and (3). Most batches have several order pick parts for which part demand exceeds the packing quantity of a pallet, box or inner unit. Hence, SLN can apply option (2). Reserve areas send for batches as many full units as possible directly to Seacon. E.g. if a pallet contains 100 parts and batch demand is 120, SLN sends a full pallet and picks 20 parts separately. Most parts must be repacked, so we add a repack function.

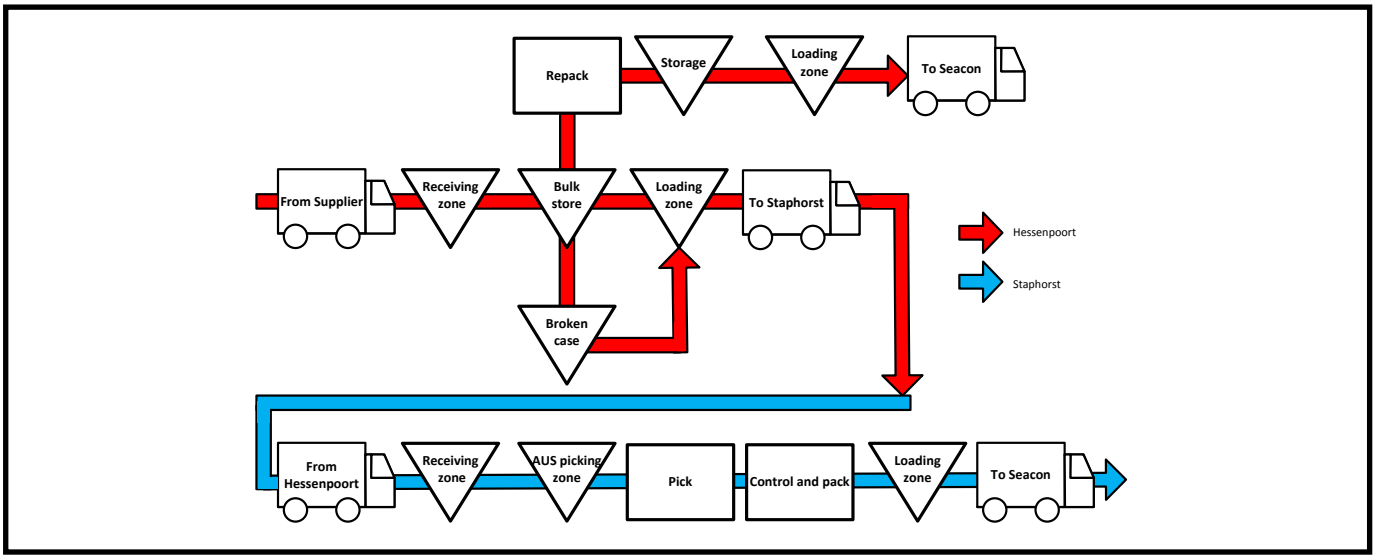


Figure 5.2 Proposed system AUS

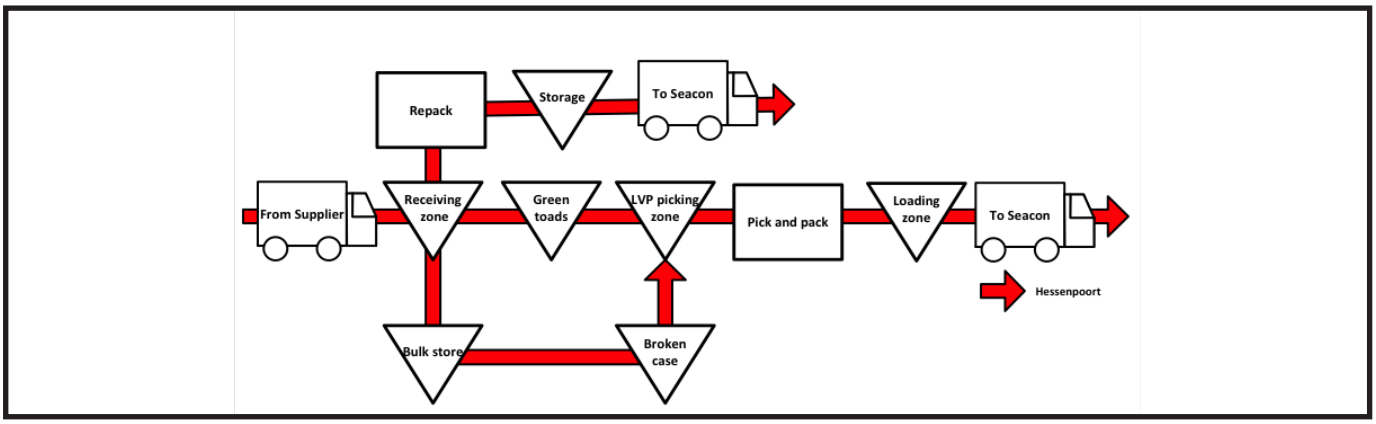


Figure 5.3 Proposed system LVP

5.3 Order pick simulation

For our analysis, we build an order pick simulation, which computes expected flow quantities and capacity requirements. One can compute averages by hand, but a simulation also shows output behaviour and statistical distributions. In addition, it is a visual tool, which allows Scania not only to hear, but also to see the simulation logic, which can give our study additional credibility.

5.3.1 Assumptions

Our simulation is based upon some assumptions:

1. Material in storage area = Material out storage area
2. Each material storage uses a Kanban system
3. Batches are always of size 6

Assumption (1) is true on long term, but not strictly on short term. There are 3000 pick parts in total, but within shorter time periods, SLN does not require them all, the simulation considers 1750 parts. This assumption allows us, together with assumption (2), to model our simulation environment as a pure kanban system. As a result, the model underestimates capacity requirements. We keep this in mind when we determine the amount of stock days.

Assumption (3) is based on demand patterns. In reality, batches have various quantities, the average ≈ 7. To delimit the model, the nearest multiple of 3, 6 is applied. As an effect, the simulation represents averages, but is less accurate towards statistical distributions of outcomes.

5.3.2 Simulation logic

Flow Quantities

The simulation considers 11 generic truck types, which represent 75% of recent demand. It contains the trucks' 1754 order pick parts and their relative chance of appearing. The user specifies desired takt and the amount of simulation-days. For each day, the model first creates for each batch the trucks produced. The model then for each day:

1. Translates the batches to material requirements for each part
2. Deducts each part's demand from its order pick stock
3. If stock<0, the stock is replenished
   a) The relevant material replenishment flow quantity is increased with one
   b) The replenishing stock decreases
   c) The same procedure applies to this stock if <0

This creates a pull system that replenishes stock points, when the stock of a material unit is down to zero. It thus determines how many material flows are needed throughout the system for each part type.

Capacity

As means of safety stock, we use Little's formula. Scania set required stock for each part as consumption for today and the following two days.

- Not each supplier delivers at Scania each day. Average supplier delay is 0.6 days (Stoffelsen, 2013)
- Our simulation does not contain all parts, but considers 1750 of 3000 parts. In addition, current parts are in the 75% of fast moving trucks. Hence the other 1250 parts are most likely slow movers.
- Material(in)=material(out) does not hold on short term, several parts (slow-movers) remain in the reserve areas or are brought back to the reserve area after a time of non-usage in pick areas.

Consumption(today)+consumption(following 5 days)

Averages are insufficient, because having enough capacity at roughly 50 percent of time is a bad service level. Hence we choose capacity such that in 95% of days, the capacity suffices.

5.3.3 Results

The simulation summarises its most important results in a box with summary statistics, such as Figure 5.3.

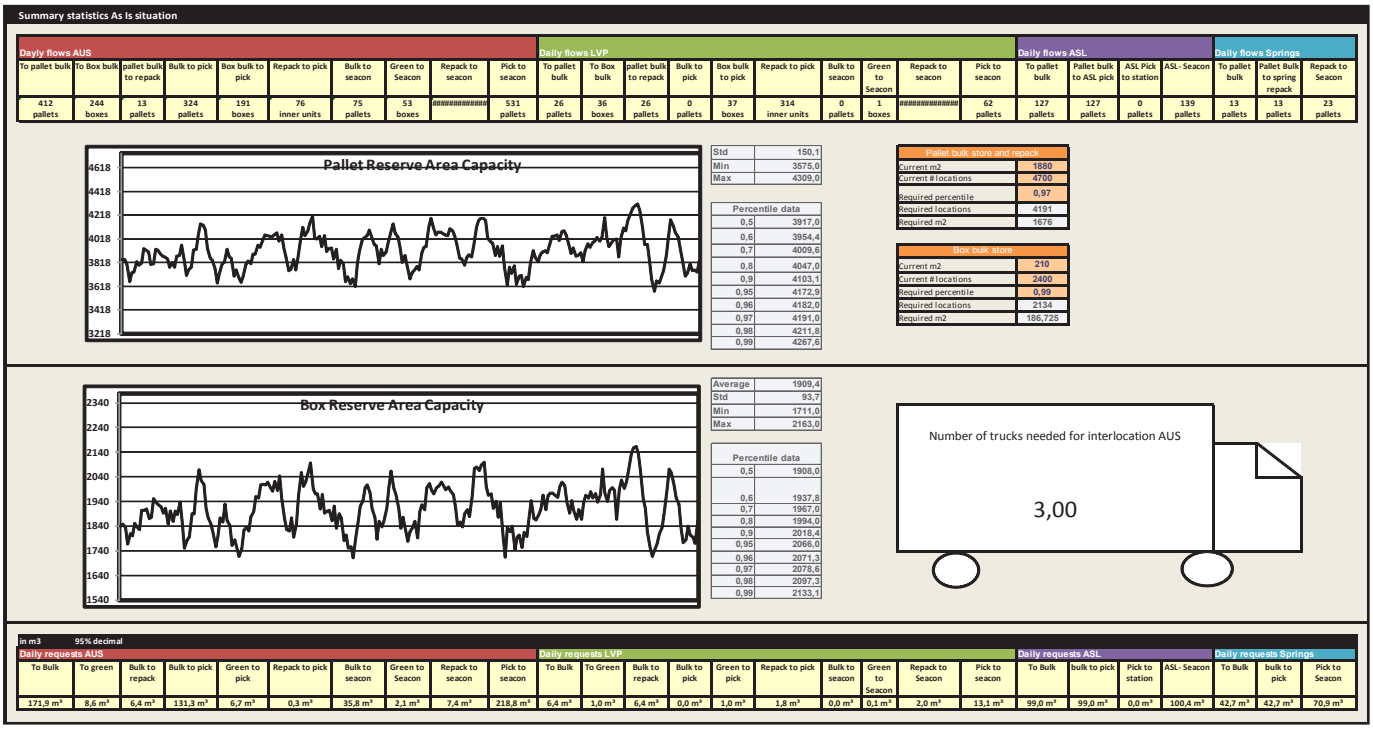


Figure 5.4 Example Simulation output

The upper table depicts the inter-department request-quantities. The lower table depicts the associated total volumes, which one can use to compute the required number of transports. Since volumes relate to capacity-usage, the table shows the 95% percentile. The truck exemplifies usage of available data. It depicts for the situation where AUS parts divided between facilities, how many trucks/day SLN needs to transport AUS parts. The graphs show how many storage locations the reserve areas require over time.

To validate our simulation, we tested several model functions:

- ***Are the outcomes face-valid?*** To test this, several people commented on the simulation results. In addition, we compared the outcomes to outcomes of other models and simulations.
- ***Usability within Scania?*** To test usability, we used several opportunities to discuss with- or present to people the added value, usability and limitations of the model.

5.3.4 Usability and limitations

Usability

The model gives some advantages to Scania. One gives as input for various common trucks material requirements for pick parts. In addition, one has to adds information such as packing quantities and volumes. Advantages include:

- It is a collection of part information unique to Scania.
- It is a visual way of describing material flows. This adds to the credibility of users.
- It gives an over-time analysis of materials flows and capacities, allowing the user to work with averages, higher decimal values and see the effect of actions over time.

Limitations

Any model represents a part of reality and this simulation does not cover the following aspects:

- It assumes batch-size 6 (the average is 7), but batches range from 3 to 18. The model takes the average into account, but not the effects of size deviations/variability.
- It assumes batches contain a single truck type. This is mostly, but not always true.
- It considers 1756/3000 parts. These are fast runners, so most of the other parts are slower movers. The model does not correct for this. So one has to be careful with directly applying stock levels.

5.4 Flows Order picking

This section presents for 36 trucks/day, the flow quantities in number of moving units and volumes in cubic metres. To calculate the flow-quantities, we assume:

- Forklift transport 3 pallets a time (Observation)
- Pallets contain 6 boxes (Observation)
- Pallets contain 23 inner unit. (Average from our simulation)
- Trucks effectively transport 68m³ (Van den Berg, 2013)

Dayly flows AUS									
To Pallet store	To Box Store	Bulk to repack	Bulk to pick	Green to pick	Repack to pick	Bulk to seacon	Box store to Seacon	Repack to seacon	Pick to seacon
407 pallets	242 boxes	13 pallets	321 inner units	189 boxes	75 boxes	73 pallets	54 boxes	15 inner units	524 pallets
Daily flows LVP									
To Pallet Bulk	To box store	Pallet Bulk to repack	Pallet bulk to pick	Box store to pick	Repack to pick	Bulk to seacon	Green to Seacon	Repack to Seacon	Pick to seacon
25 pallets	36 boxes	25 pallets	0 inner units	37 boxes	312 boxes	0 pallets	1 boxes	322 inner units	62 pallets
Daily flows ASL				Daily flows Springs					
To Pallet Bulk	Pallet Bulk to pick	Pick to station	ASL- Seacon	To Pallet Bulk	Pallet Bulk to pick	Pick to Seacon			
126 pallets	126 pallets	0 pallets	138 pallets	13 pallets	13 pallets	23 pallets			

Table 5.2 Daily requests in number of pallets/boxes/inner units

Dayly requests AUS									
To Pallet store	To Box Store	Pallet Bulk to repack	Bulk to pick	Green to pick	Repack to pick	Bulk to seacon	Box store to Seacon	Repack to seacon	Pick to seacon
172.0 m³	8.4 m³	6.4 m³	130.6 m³	6.6 m³	0.3 m³	36.4 m³	2.1 m³	7.1 m³	221.5 m³
Daily requests LVP									
To Pallet Bulk	To box store	Pallet Bulk to repack	Pallet bulk to pick	Box store to pick	Repack to pick	Bulk to seacon	Green to Seacon	Repack to Seacon	Pick to seacon
6.4 m³	1.0 m³	6.4 m³	0.0 m³	1.0 m³	1.8 m³	0.0 m³	0.0 m³	2.0 m³	12.1 m³
Daily requests ASL				Daily requests Springs					
To Pallet Bulk	Pallet Bulk to pick	Pick to station	ASL- Seacon	To Pallet Bulk	Pallet Bulk to pick	Pick to Seacon			
97.6 m³	97.6 m³	0.0 m³	100.4 m³	42.7 m³	42.7 m³	66.4 m³			

Table 5.3 Daily requests in cubic metres

We apply the output and assumptions to calculate the number of required trucks (in case of between locations transport) and forklifts (in case of within location transport). Figures 5.4 depicts the resulting material flow quantities.

cap per supply method	Truck									
	To Pallet store	To Box Store	Bulk to repack	Bulk to pick	Green to pick	Repack to pick	Bulk to seacon	Box store to Seacon	Repack to seacon	Pick to seacon
AUS	2.53 trucks	0.12 trucks	0.09 trucks	1.92 trucks	0.10 trucks	0.00 trucks	0.54 trucks	0.03 trucks	0.10 trucks	3.26 trucks
LVP	0.09 trucks	0.01 trucks	0.09 trucks	0.00 trucks	0.01 trucks	0.03 trucks	0.00 trucks	0.00 trucks	0.03 trucks	0.18 trucks
ASL	1.44 trucks	-	-	1.44 trucks	-	-	-	-	-	1.48 trucks
Springs	0.63 trucks	-	-	0.63 trucks	-	-	-	-	-	0.98 trucks
cap per supply method	Forklift									
	To Pallet store	To Box Store	Bulk to repack	Bulk to pick	Green to pick	Repack to pick	Bulk to seacon	Box store to Seacon	Repack to seacon	Pick to seacon
AUS	135.6 rides	13.5 rides	4.3 rides	106.9 rides	10.5 rides	1.7 rides	24.4 rides	3.0 rides	0.3 rides	174.6 rides
LVP	8.5 rides	2.0 rides	-	0.0 rides	2.0 rides	6.9 rides	0.0 rides	0.0 rides	0.0 rides	20.7 rides
ASL	42.0 rides	-	-	42.0 rides	-	-	-	-	-	46.1 rides
Springs	4.3 rides	-	-	4.3 rides	-	-	-	-	-	7.6 rides

Table 5.4 Daily request in number of pallets/boxes/inner units

5.5 Flows Dedicated parts

Dedicated parts have the following average quantities per day at the 18 trucks/day to 48 trucks/day:

	Trucks/day	18	24	30	36	42	48	Surface	Volume
Main Flow	Engine	11	15	18	22	26	29	3.26 m²	3.13 m³
	Axle	30	40	50	60	70	80	2.07 m²	3.13 m³
	Gearbox	11	15	18	22	26	29	1.33 m²	1.28 m³
Exernal Sequence	Set of tiers	14	19	24	28	33	38	1.34 m²	3.09 m³
	5th tier	8	10	12	15	17	20	1.34 m²	3.09 m³
	fuel tanks	33	44	54	65	76	87	1.33 m²	1.28 m³
	Others	36	48	60	72	84	96	1.50 m²	1.50 m³

Table 5.5 Average Main Flow & External Sequence demand levels

Main Flow

SLN handles three Main Flow parts for non-Russian markets: Engines, axles and gearboxes. Each truck has an engine, a gearbox and on average 2.75 axles (te Winkel & van den Berg, 2013). Table 5.5 shows Scania processes 104 parts/day at a takt of 36 trucks day (our assumption). They flow from a truck to the unloading area, to a WIP area, to the workstation, to the loading area and finally back in the truck.

External Sequence

To group External Sequence parts, we use the classification by Van den Berg (2013) in tier sets, fifth wheels, fuel tanks and "others". Table 5.5 shows Scania on average processes 180 parts/day at 36 trucks/day (the assumed takt). They flow from the receiving area, to the storage area, to the production area and finally to the loading area.

5.6 Flows and capacity Box store Scania Production Zwolle

Chapter 2 mentions the Zwolle Boxes will move to Hessenpoort. The project is still starting-up and clear data is still unavailable. We spoke to the head of the project group. He could not give us details yet, but mentioned:

1. He expects Scania will use one vehicle to execute a shuttle service. Each hour this vehicle:
   - Goes from Scania Production Zwolle with pallets for SLN to store
   - Unloads this new MUs and picks up the picked parts.
   - Brings the Picked parts to Scania Production Zwolle.
2. The vehicle used for this shuttle service has a capacity of ca. 20 m³.
3. He expects required floor capacity is ca. 2500 m².

So, 15 times/day a vehicle arrives with surface = 20 m³. If we assume average fill rate = 85% (rule of thumb), expected total volume = 85%*20*15=255 m²/day. Because this area has the same parts as the SLN box reserve area, we take the average ride from Receiving to the Box Reserve Area. A daily total of 9.4 m³ is transported, this takes 7.7 rides.

The volume per forklift ride is 1.22 m³. It then takes on average 255/1.22≈209 forklift rides to transport the boxes to Hessenpoort and another 209 rides to take it to Scania Production Zwolle.

5.7 Packaging

5.7.1 Packaging for final products

Recall the packaging project: A supplier gets 50 m² per location to build and distribute packaging materials. Order pick processes need built-up packaging and dedicated processes non built-up packaging. Again 6 boxes or 23 inner units account for a pallet. Empty pallets are lighter than full ones, so we assume forklifts transport built-up packaging by four at a time. Non built-up packaging is harder to estimate, but we estimate forklifts take 10 at a time. Then the following quantities are required:

Part type	Required pallets	How delivered to station?	# rides
LVP pick	62	Built-up	15.5 rides
AUS pick	531	Built-up	133 rides
Pallet to Seacon	75	Built-up	18.8 rides
Repack to Seacon	14.8	Built-up	3.7 rides
Boxes to Seacon	9	Built-up	2.3 rides
ASL	139	Built-up	34.8 rides
Springs	23	Built-up	5.6 rides
External Sequence	180	Non built-up	18 rides
Main Flow	106	Non built-up	10.6 rides

Table 5.6 Average number of required pallets from the packaging supplier

5.7.2 Packaging return flows

Empty packaging is a side product of KD production. The number of empty material units equals the number of new material requests. All boxes and pallets have to be returned. Our simulation input data shows 33% of the inner units are returnable. Our simulation and flow analysis yield:

- Boxes and inner units go in 2 m³ pallets and have an average volume of 0.027 m³. Hence, a pallet carries 74 units. These are large pallets; forklifts transport them by only one a time. Hence we assume the number of internal rides =(# boxes)/74.
- Return flow reusable pallets go to the packaging area. Russia (40% of demand) uses these pallets, so SLN reuses them for Russian batches. Employees indicate that the number of reusable pallets in the return flow equals the Russian demand.
- Main Flow parts arrive on racks. When the racks are empty, the supplier removes them.
- The percentage External Sequence parts with returnable packaging is negligible. We assume this is 10%.

Part type	Required pallets	Required Rides (forklift)	Sum of return flows	New Packaging supply	Max*1.1
LVP Picking	37 boxes 104 inner units	0.5 rides 1.4 rides	1.9 rides	15.5 rides	17,1 rides
AUS Picking	324 pallets 191 boxes 25 inner units	81 rides 2.6 rides 0.3 rides	83.9 rides	133 rides	146.3 rides
Pallet Repack	39 pallets	9.8 rides	9.8 rides	3.7 rides	10.8 rides
Pallets to Seacon AUS	75 pallets	18.8 rides	18.8 rides	18.8 rides	20.7 rides
Boxes to Seacon LVP	1 box	0.0 rides	0.7 rides	9 rides	9.9 rides
Boxes to Seacon AUS	53 boxes	0.7 rides			
Inner-units to Seacon LVP	109 inner units	1.5 rides	1.6 rides	14.8 rides	16.3 rides
Inner-units to Seacon AUS	5 inner units	0.1 rides			
ASL Picking	127 pallets	31.8 rides	31.8 rides	34.8 rides	38.3 rides
Springs	13 pallets	3.3 rides	3.3 rides	5.6 rides	6.2 rides
External Sequence	18 pallets	4.5 rides	4.5 rides	18 rides	19.8 rides
Main Flow	106 units	21.2 rides	21.2 rides	10.6 rides	23.3 rides

Table 5.7 packaging rides

5.7.3 Combined packaging flows

We assume that as much as possible, the packaging supplier avoids empty rides by taking new packaging to workstations and taking return flow back to the packaging area. Due to timing/availability this is not always possible. We assume the number of required movement = max(ride to station,ride from station)*1.1.

5.8 Chapter 5 summary & preview

In summary, chapter 5 calculated for all functions the inter-function flows and answers Research Question 5:

"Which activities will take place at SLN and which material flows will they create?"

SLN executes the following activities (See also Table 5.1):

Orderpick parts	Dedicated parts	Other
Combined reserve area	Main Flow Handling	Zwolle Boxes
LVP Picking	External Sequence parts handling	Cross dock function
AUS Picking		
ASL Picking		
Springs Picking		

Table 5.6 Required SLN activities

For calculating the order pick flows, we use our simulation. A numerical analysis was made to calculate dedicated flows. Figures 5.4 and 5.5 give a visualization of the various flows. The flows between workstations are black, except the flows from/to the packaging area, which are red. The only reason for this is to make the image clearer (with several flows crossing each other). Dedicated and order pick processes have a different figure for the same reason. The displayed flows are flows going between (back and forth) the stations; they are no one-way flow.

One can e.g. see in these images that AUS is the most dominant order pick part-type and that the flows to/from outside and the loading and unloading areas are dominant. One conclusion can be that one wishes to place loading and unloading areas close to entrances of the building, since these are large flows.

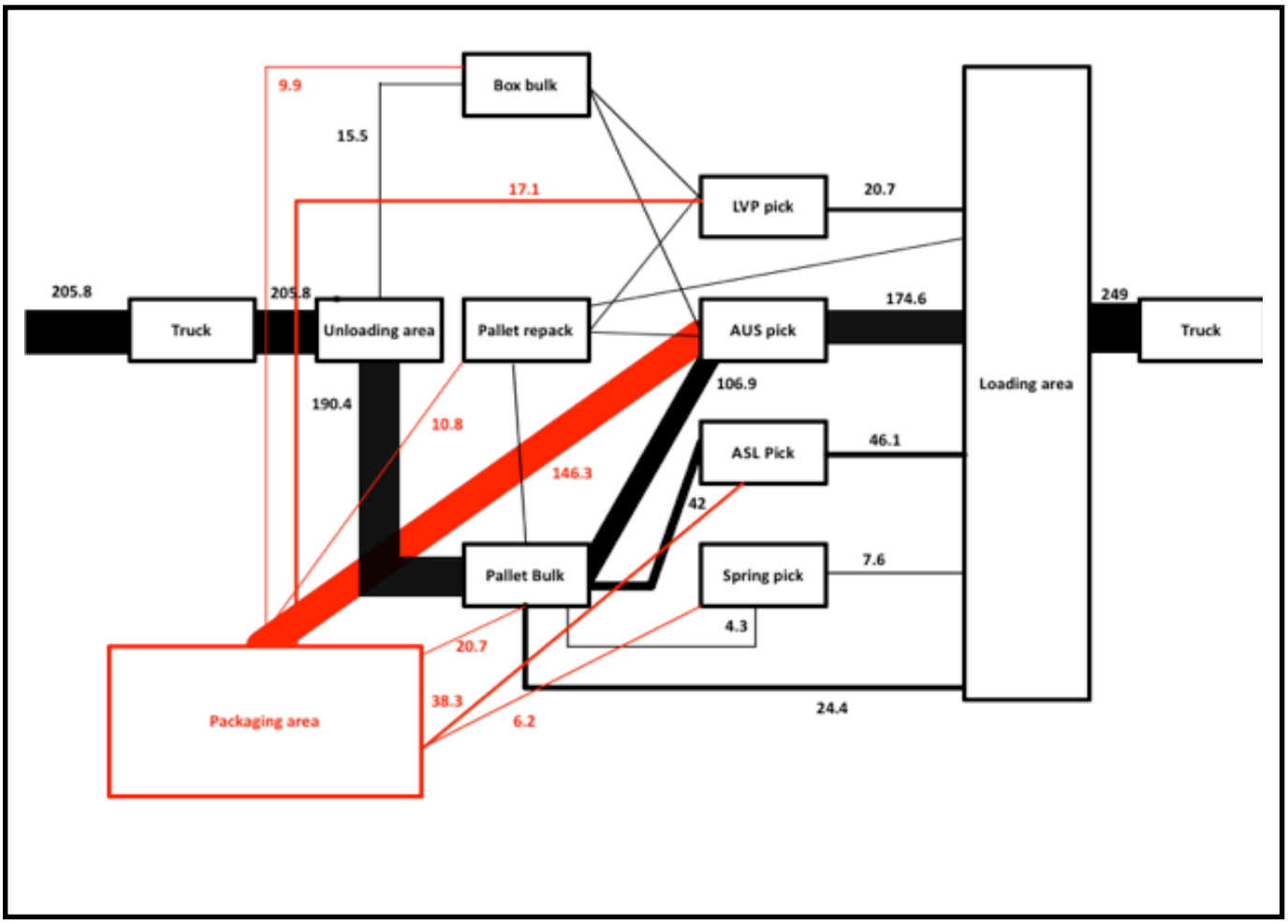


Figure 5.4 Relationship diagram of orderpick functions and packaging

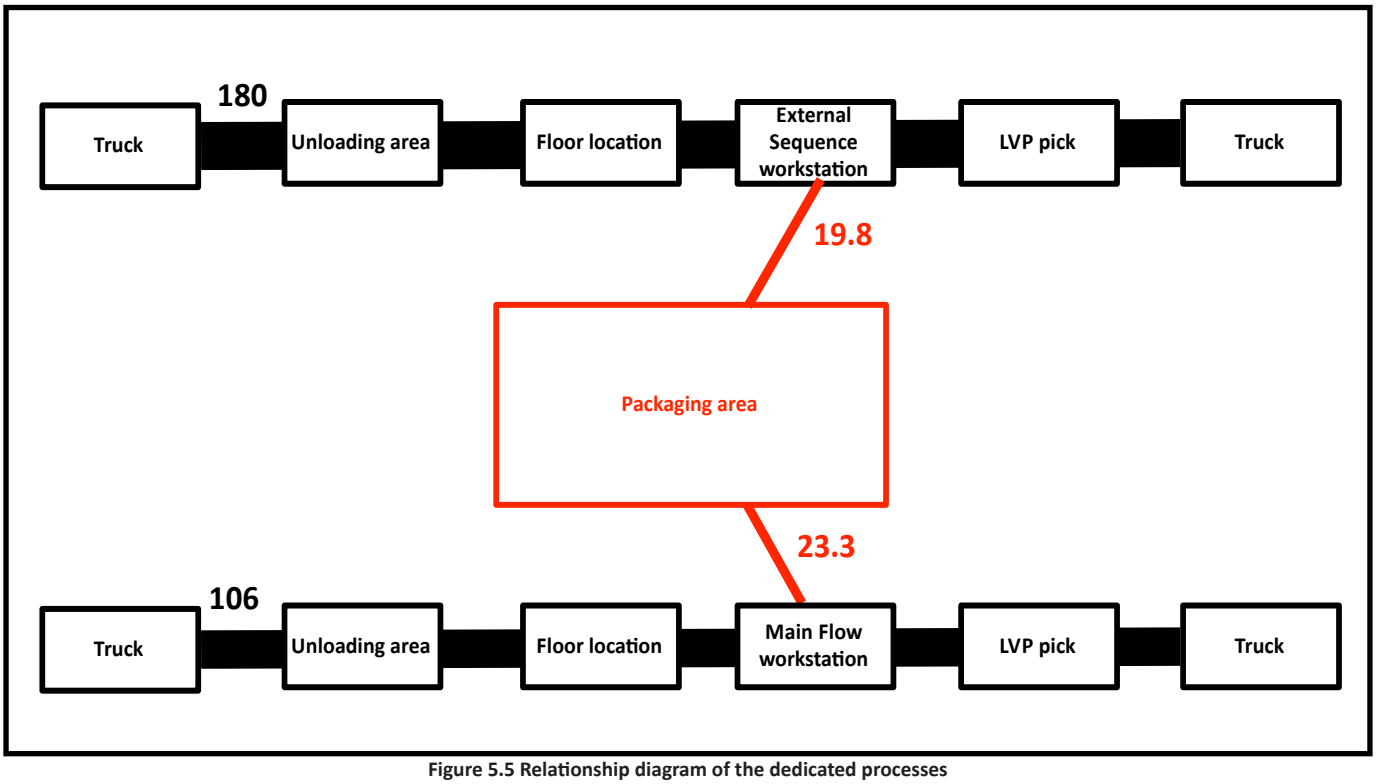


Figure 5.5 Relationship diagram of the dedicated processes

6. Required capacity

Chapter 5 starts the SLP analysis phase by identifying inter-station flows. Chapter 6 determines the associated capacity requirements. Section 6.1 treats order pick parts and Section 6.2 dedicated parts. Section 6.3 treats the Zwolle Boxes and the packaging area. Chapter 6 answers Research Question 5:

"How much capacity does each activity require and how does this relate with SLN's total capacity?"

6.1 Capacity Order pick parts

6.1.1 Method

To determine the capacity requirements for the Pallet Reserve Area, the Box Reserve Area, AUS picking and ASL picking, we use the converting method (Muther , 1967). This method converts the current capacity to the new required capacity. In our case, we determine the current m²/storage location, including functions such as work in progress, disposal and aisles. We use de Ruiter (2013) and Wessels (2013) to find the number of storage locations. The subsections expand on the required number of locations. We always apply Required m² = (current m²)/(m² per location)*required number of locations. Figure 6.1 depicts the capacity requirements.

Area	Current m²	Current # locations	m² per location	Required # locations	Required m²
Pallet Reserve Area	1900 m²	4700 locations	0.4 m²/location	5350 locations	2122 m²
Box Reserve Area	240 m²	2400 locations	0.1 m²/location	2600 locations	260 m²
AUS picking storage	3550 m²	5408 locations	0.66 m²/location	2200 locations	1450 m²
ASL picking storage	400 m²	0650 locations	0.62 m²/location	223 locations	139 m²

Table 6.1 Areas and their capacity requirements

6.1.2 Pallet reserve area and pallet repack area: 2122m²

Chapter 5 sets the required capacity to six days and Figure 6.1 depicts the simulated capacity requirements. If SLN does not alter its stock policy, 5350 locations suffice ca. 97% of the time. Frequent removing of obsolete parts can further improve the service level. Table 5.1 yields the Pallet Reserve Area needs 2122 m², which is close to the current capacity. This seems valid; the reserve area was planned for 48 trucks/day

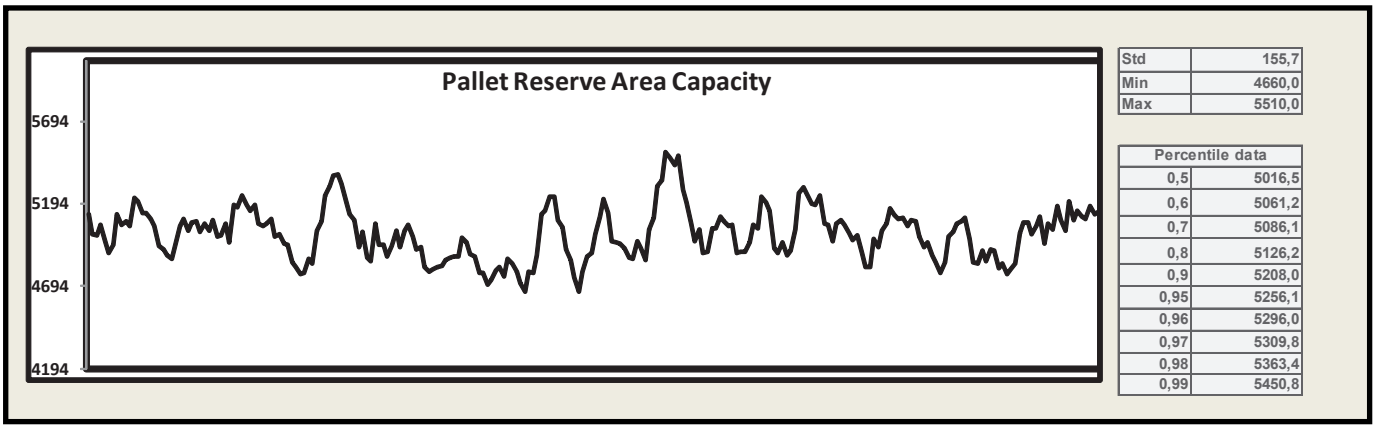


Figure 6.1 Combined capacity requirements pallet reserve area and pallet repack area

6.1.3 Box Reserve Area: 240 m²

Figure 6.2 depicts the simulated capacity requirements for six days. Currently, 2600 locations suffice ca. 97% of the time. Frequent removing of obsolete parts can further improve the service level. Table 5.1 yields SLN needs 260 m², which is close to the current capacity. This seems valid; the reserve area was planned for 48 trucks/day. A contradicting element is that currently, occasional shortages occur. However in current situation some location types have shortages, while other types still have free capacity.

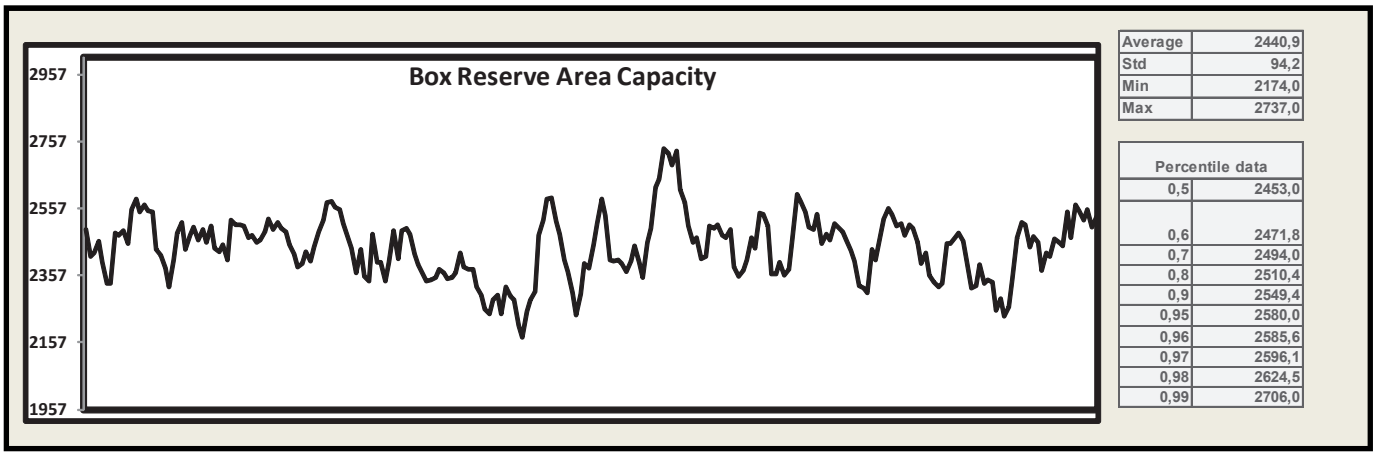


Figure 6.2 Capacity requirements Box Reserve Area

6.1.4 LVP Picking: 350 m²

LVP Picking has 350 m² and 800 locations. When the takt grows to 48 trucks/day, the throughput in picking parts also grows. This could mean SLN needs more locations, but we see some counteracting factors:

1. The LVP Russia project (Section 2.6) aims at a situation where SLN picks no LVP parts for Russia, which is 40% of the market, so this means a similar reduction in LVP Picking.
2. Our proposal to send full pallets or inner units for each part type. Figure 6.3 depicts the number of LVP pallets, which the pick area sends to Seacon. We see the number of pallets for 48 trucks/day in the proposed system is lower than for the current system at 24 trucks/day.

Our simulation does not consider the former. We expect both projects weaken each other's effects. Nevertheless we see the LVP pick throughput can shrink, while the takt doubles. Hence, we deem the current 350 m² of sufficient to handle 48 trucks/day.

Takt	Current system	Proposed system
48	140	78

Table 6.2 Number of LVP pallets in the current system and proposed systems

6.1.4 AUS Picking: 1930 m²

Storage area: 1450 m²

AUS Picking uses kanban to manage stock levels: Each available part has at least two pallets/boxes. So non-used parts, which SLN does not remove, occupy at least two locations. This does no justice to the available demand information. Hence we propose to drop the kanban system and to use the following logic:

KD has ca. 1800 AUS parts. Our simulation shows 3% of pallets/boxes is exactly empty after a day. The others are still partly filled or a new pallet was needed, which is still partly filled. Hence AUS picking occupies ca. 1750 locations at the end of a day. We propose SLN brings extra material units only for the parts that have insufficient rest inventory for current demand and brings each time the minimal amount of extra required units. On busy days (95% decimal) ca. 900 pallets and boxes go from reserve areas to AUS Picking (See our simulation). If SLN plans capacity for at least a ¼ of daily usage, it requires 2200 locations. Table 6.1 yields SLN then needs ca. 1450 m².

One effect is not taken into account: SLN will implement zoning in its warehouse, which is more dedicated. Dedicated systems require more storage capacity (Barholdi and Hackman, 2010). We however assume potential effects are counteracted by the fact that pickers start emptying the warehouse, while forklifts bring new pallets and boxes.

Workstations: 480 m²
AUS packing uses 300 m² and was designed for 48 trucks/day. Employees indicate this capacity should be nearly enough, but an increase might still be necessary. An additional area was initially reserved for packing, SLN can increase the station's to 480 m², these employees are sure this suffices at 48 trucks/day. We follow their experience and set workstation requirements for AUS Picking to 480 m².

Total: 1930 m²
The total required capacity is 1930 m². This is considerably less than the current capacity. This is largely due to the kanban system, which requires more pallets in storage, which SLN does not use each day. The proposed system largely elevates this effect.

6.1.5 ASL Picking: 339 m²

SLN needs ASL pick capacity for:

1. Storage
2. A workstation

Order pick Storage: 139 m²
For ASL, we propose the same logic as we do for AUS. This means to drop kanban and to only store for demand in the coming hours. KD has ca. 180 ASL parts. If again 3% is empty after a day, 175 pallets remain. 189 pallets go from the Pallet Reserve Area to ASL Picking on busy days (95% percentile). If SLN sets capacity to remaining pallets + a quarter daily usage, it requires 223 locations. Table 5.1 yields ASL picking then requires 139 m².

Workstation: 200 m²
The ASL workstation uses ca. 100 m² and already functions at 24 trucks/day. During conversations with responsible managers, we asked if they thought the workstation appropriate for 48 trucks/day. They deem current capacity insufficient and estimate the current capacity suffices for 30 trucks/day. We assume 200 m² (including walking and work in progress areas) suffices to handle 48 trucks/day.

Total: 339 m²
ASL Picking needs 139 m² for storage and 200 m² for order picking. In total it needs 339 m²

6.1.6 Spring Picking: 225 m²
The current spring station has 250 m² and includes production and a storage area. The storage has capacity for 12 pallets.

Storage: 25 m²
Our simulation considers ten types of springs. If we again correct for the total number of parts, we expect 17 part numbers. The storage comprises 20 locations and 25 m². Part numbers are always present, thus 20 locations should suffice. If the takt rises, the number of replenishments can rise to compensate for an increase in parts.

Production: 200 m²
The current workstation uses ca. 100 m² and already produced 24 trucks/day. Our- and employees' estimations indicate this capacity is insufficient for 48 trucks/day. Given one station can already produce 24 trucks, two workstations suffice to accommodate 48 trucks. The workstation capacity then grows to 200 m².

Total: 225 m²
The total amount of required capacity is 25 + 200 = 225 m².

6.2 Dedicated parts

6.2.1 Main Flow: 650 m²

Capacity
Main Flow needs capacity for:
1) Receiving
2) Production & work in progress
3) Loading area

Receiving: 63.3 m²
To analyse Receiving logic, we analyse data (Scania, 2013). Unfortunately, only 15 days of data are available. It shows trucks always transport 24 parts/truck: either 24 axles or 12 engines & 12 gearboxes. At 48 truck/day, on average 5.7 trucks/day arrive at SLN. 2.4 trucks with engines/gearboxes and 3.3 trucks with axles.

SLN can manage these arrivals, especially since the parts are stored near Staphorst (Nieuwleusen). Due to this plan ability, we assume Receiving capacity for 2 trucks suffices. Trailers with axles require 16.6 m² and trailers with engines/gearboxes 47.1 m² of floor capacity. The latter requires more capacity, but the former appears more often. We assume Scania requires capacity for one truck of both. Total required Receiving capacity = 63.6 m².

Production & work in progress: 500 m²
At present, Main Flow has 100 m² production and 150 m² work in progress. Employees indicate this single workstation is insufficient for 48 trucks/day. Scania already used the workstation for 24/day, so we assume an extra workstation + work in progress suffices at 48 trucks/day, which is our maximum demand. Hence, Main Flow production and work in progress require 500 m².

Loading area: 63.3 m²
Several trucks a day go to Seacon, they are not necessarily presents when a truckload is ready, but Scania can plan them beforehand. Therefore we assume the outbound area needs capacity for 2 trucks. We again assume one trailer with axles and one with engines/gearboxes. Considering the capacity requirements for the trucks, total required Receiving capacity is 63.3 m².

Total: 650 m²
Total required floor surface is 618.8 m², excluding capacity for walking areas. We assume making total required capacity 650 m² should suffice to accommodate this. Current working area is smaller, but has only been used for a takt up to 24 trucks/day.

6.2.2 External Sequence: 700 m²

Receiving capacity: 90 m²
We analyse External Sequence deliveries in 34 days with a takt varying between 18 and 24 trucks/day. Most days, between three and six trucks arrive. Most arrivals are spread throughout the day, by exception three trucks arrive within an hour. This is due to Hessenpoort using timeslots. At present, most trucks are less than half full, the only External Sequence full truck are trucks carrying tiers. At 48 trucks/day, SLN requires 6.4 full trucks. We expect SLN, when applying time slot management does not have to receive more than 3 trucks a time. Thus, 3*30=90 m² suffices.

Capacity for storage: 250 m²
External Sequence parts require storage capacity before going to the workstation. SLN keeps 1.5 days of safety stock for dedicated parts. I.e. parts arrive today, which Scania processes the day after tomorrow. Multiplying average production quantities with their floor space requirements yields:

Trucks/day	18	24	30	36	42	48
m2/day	127	169	210	252	294	337
1.5 day	191	254	315	378	441	506

Table 6.3 External Sequence Floor Surface

Currently, with a takt varying between 18 and 24 trucks/day, 250 m² is needed. With the current number of parts/truck, storage requires ca. 500 m². Recall, however, that External Sequence will shrink and eventually disappear. We expect 350 m² suffices; if the function does not shrink, it allows the takt to rise to 30 trucks/day. We expect a growth to above 30 trucks/day will take long enough to reduce the External Sequence function.

Production and work in progress: 200 m²
The workstation uses 700 m² and is divided in two. In one half employees repack the parts. Upon finishing, they go to the other half. Meanwhile, forklifts already placed new parts to repack in this half. When the packers work in the new half, forklifts replace the 'old' half's finished parts with new parts, waiting for the packers to finish at the other half. This means one half serves as production and the other as work in progress.

The capacity seems extensive; current daily demand fits on only one part. We propose to assign each sections 100 m². When half a section is filled with parts, it has capacity for ca. 35.7 parts and leaves 50 m for personnel, machinery and work in progress packaging materials.

Loading area: 60m²
SLN plans the pickup moments for External Sequence parts. Therefore we assume capacity suffices when the area can contain two trucks. That is 2*30=60 m².

Total capacity: 700 m²
Total required floor space is 90 + 350 + 200 + 60 = 700 m²

6.3 Capacity Zwolle Boxes:2500 m²
Chapter 5 discusses the capacity and flows of the Zwolle Boxes. The project team's projection is that 2500 m2 is required. Since little information is available, we assume the assumptions of the project team correct.

Chapter 3 introduces the packaging project and mentions SLN's Requests For Quotation define suppliers get 50 m2 per location to build-up and store packaging materials. Since several suppliers compete for this, we assume SLN's requirements are reasonable.

6.4 Conclusion & Preview
Chapter 6 answers Research Question 5:

"How much capacity does each activity require and how does this relate with SLN's total capacity?"

The chapter yields the following capacity requirements per function (Figure 6.5):

Overview capacity requirements	
Pallet reserve area + Pallet repack area	2140 m²
Box reserve area	260 m²
LVP Picking	350 m²
AUS Picking	1930 m²
ASL Picking	339 m²
Spring Picking	225 m²
Unloading area order pick	150 m²
Loading area order pick	150 m²
Main Flow handling	650 m²
External Sequence handling	700 m²
Packaging area (x2 locations)	100 m²
Box reserve area Scania Production Zwolle	2500 m²

Table 6.4 overview capacity requirements

Total required capacity is ca. 9200 m², where Staphorst has ca. 6000 m² and Hessenpoort ca. 7500 m². The total of 13,500 m² suffices to handle all activities. In addition: The total required order pick capacity is ca. 5550 m². This is less than the total capacity of Staphorst or Hessenpoort separately.

Chapter 6 concludes the analysis, so Chapter 7 continues this study with the Search and Evaluation phases. It creates three layout scenarios and subtracts from them practical recommendations.

7. Layout scenarios

Chapters 5 and 6 conduct the SLP Analysis phase. Recall the other phases are Search and Evaluation: the planner comes up with layout alternatives, which he/she evaluates. Chapter 7 searches the theoretically optimal layout alternatives for 3 scenarios and answers Research Question 6:

"How can SLN redesign its layouts and how do the changes affect SLN's performance?"

Section 7.1 discusses the layout methodology. Section 7.2 depicts the current system costs and the cost of the proposed system with the Zwolle Boxes at Hessenpoort. Section 7.3 treats Scenario I, which does not consider the Zwolle Boxes and uses Hessenpoort/Staphorst. Section 7.4 treats Scenario II, which adds to Scenario I the Zwolle Boxes. Section 7.5 treats Scenario III, which is equal to Scenario II but places its departments in a Green Field area. Section 7.6 reviews the results of the various scenarios and Section 7.7 applies characteristics of the theoretical solutions to practice.

7.1 Methodology

Chapter 7 uses several assumptions and tools. Section 7.1 introduces them. Subsection 7.1.1 introduces the assumed between-locations transport costs and the internal material handling costs and Subsection 7.1.2 introduces the used tools.

7.1.1 Cost measures

Between-locations transport € 78.-/hour

Current transport costs are €130.-/hour (Te Winkel & van den Berg, 2013). It includes loading, transport and unloading. Most European trucks are 40-tonners, based on observation, we assume (un-)loading a 40-tonne truck takes 30 minutes. To attain travel-times between locations we use a route planner which can compute truck routes. SLN is currently setting out a tender to reduce these costs. The head logistics expects to cut 40% of the costs. If so, hourly costs are € 78.-.

Internal Transport € 32.81/hour

Forklifts usually provide internal transport, they cost € 7.81/hour and personnel costs € 25/hour. (Scania, 2013). A forklift with driver costs € 32.81/hour. If we assume forklift-drivers to effectively work 80% of the time, then the effective rate is € 41.01/h = 1.14 cents/s. The maximum forklift speed within buildings is 8 km/h (Scania, 2004). Considering this is a maximum speed, we estimate 5 km/h = 1.39m/s as average speed. Hence costs are 1.14/2.22=0.82 cents/meter.

7.1.2 Tools: System level costs, MULTIPLE, CRAFT

Chapter 4 mentions several theoretical insights and methods to apply and states we combine MULTIPLE and CRAFT to create and improve the layouts, where MULTIPLE creates the input for CRAFT. To accommodate this, we use several Excel based tools, viz., Transport cost overviews for various scenarios and tools which apply for the relevant locations first MULTIPLE and then CRAFT.

System level cost overviews

The first tool depicts the system level. One gives the between-facilities flows resulting from the division of activities and the tool calculates the transport costs, given the mentioned € 78.-/hour. This method is a mild form of Uniform Graph Partitioning.

MULTIPLE-tool

The second tool executes MULTIPLE. It first translates the departments' capacity requirements to grid-quantities (It also accounts for the total required capacity being lower/higher than the total capacity). It starts with a certain sequence to make a facility layout. Subsequently, simulated annealing randomly interchanges departments (again

the tool creates layouts). In addition to basic Simulated Annealing, the algorithm registers “good” goal function values, which the user adapts according to the found values.

A curve is the basis for MULTIPLE, ours are no Space Filling Curves, for they are not continuous; they sometimes leave the facilities. This is partly due to the facilities’ overall shapes and physic constraints such as walls and doors. Our curves were found by trial and error. Curves which more resemble the ‘real’ Space Filling Curves yield stranger department shapes and our curves have face-valid flows through the facilities.

Figure 7.1 Hessenpoort curve

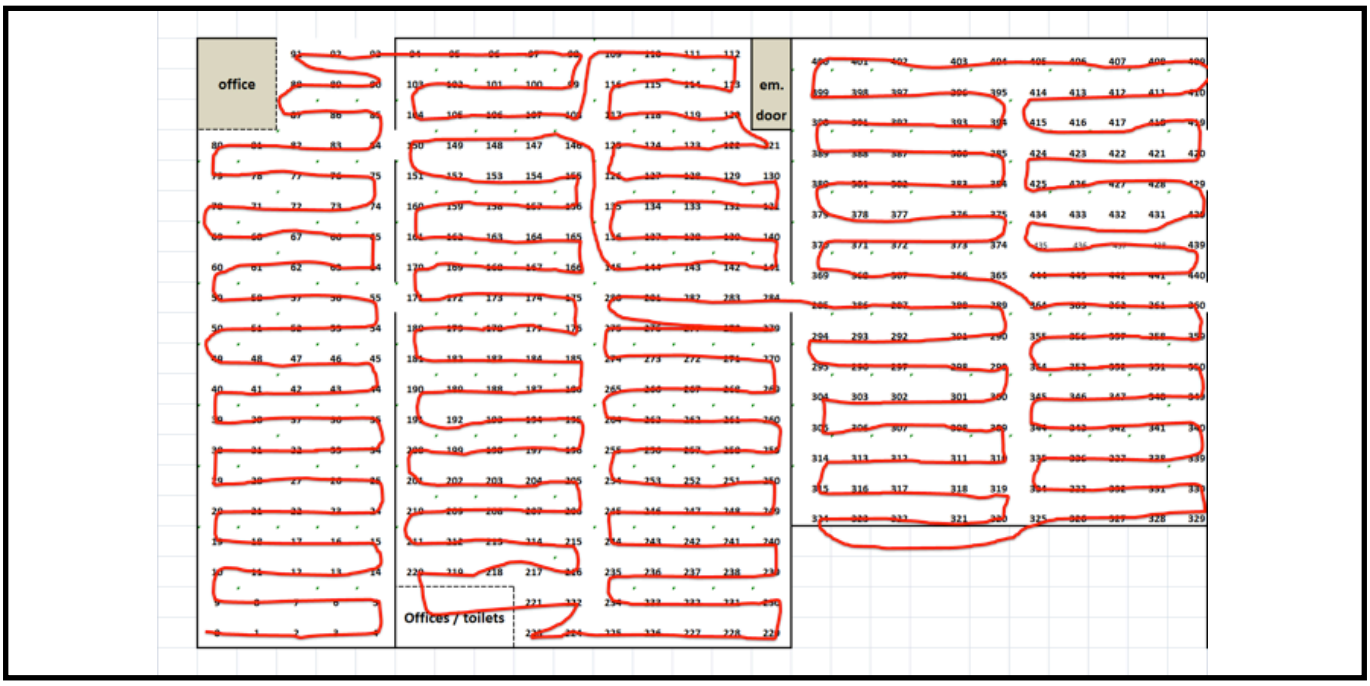


Figure 7.2 Staphorst curve

At Staphorst, we use at most the first 3 halls, therefore Figure 7.3 displays these halls and the Curve within these halls. For the Green Field case, we use a curve which more resembles the Space Filling Curve, since here we do deal with a square facility.

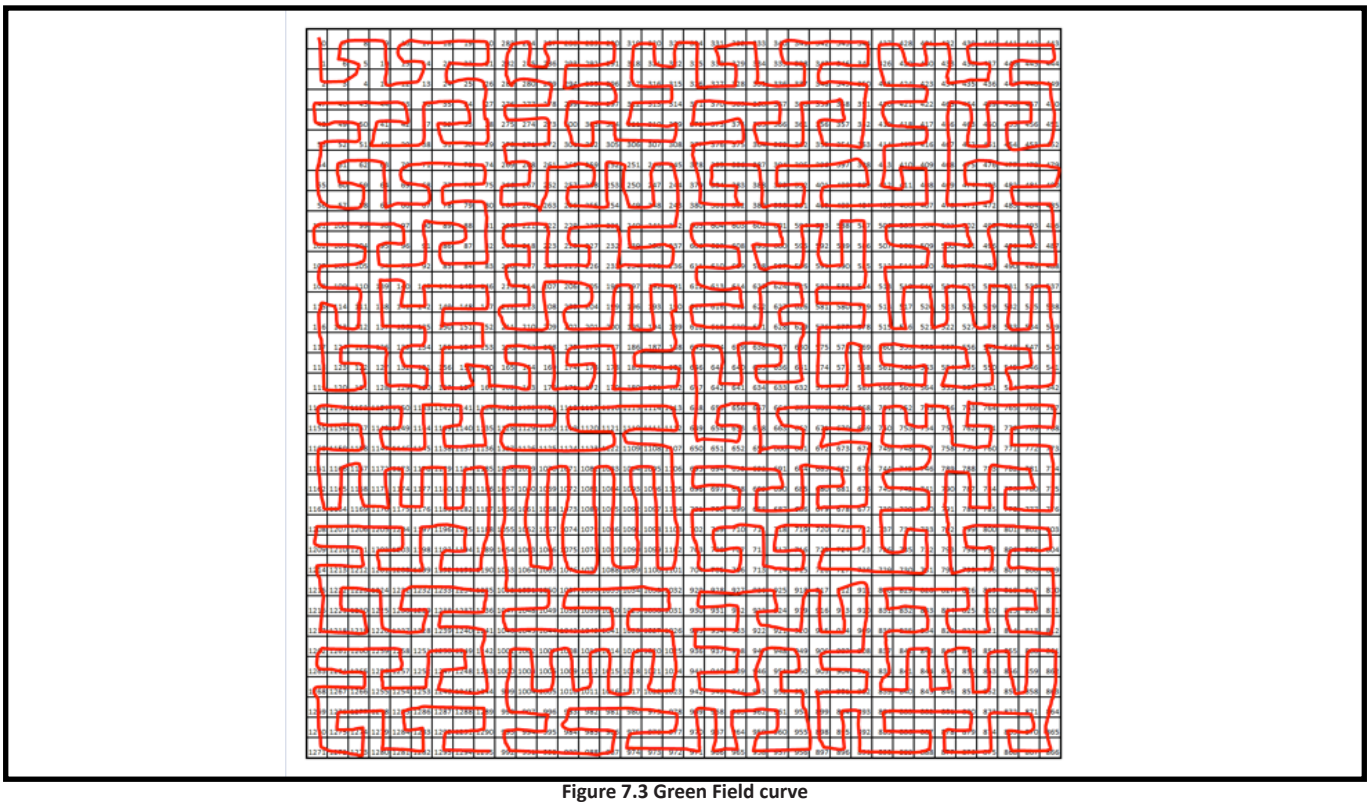


Figure 7.3 Green Field curve

After Simulated Annealing stops, the sheet displays a top 10 of found values. The user can visualize these solutions to assess their face validity. If the user finds a satisfactory solution, he/she 'repairs' illogical department shapes and copies the layout to the CRAFT tool.

CRAFT-tool

In the CRAFT tool, the user uses the basic solution to estimate department midpoints. He/she fills in the relevant depart numbers in their midpoints. The algorithm calculates the (Manhattan) distances and the objective value. Both MULTIPLE and CRAFT give no 100% accurate values, as they cannot translate the system's full behaviour. E.g. they cannot model that for storage/picking areas, one first exits the current aisle, goes to the destination aisle and enters it. The models simply calculate basic distances.

To perform iterations, one swaps the departments in the sheet, determines the new midpoints and enters their numbers in the relevant cells. The algorithm again estimates the goal function value. This method is subjective, since users can estimate various midpoints for the same department. On the other hand, this provides flexibility; the user can test many changes, even changes with no department interchange such as a shifting department midpoint. In addition, the user can easily discuss the midpoint with peers to reach mutual agreement.

7.2 Costs of the current layouts and the planned alternative

This section explicates the costs of the current SLN layouts, so that this chapter can compare the results of the optimized situations. Subsection 7.2.1 treats the current layout and Subsection 7.2.2 the layout with the changes Scania is planning.

7.2.1 Current layout: KD costs € 2,089,406.-

The Current situation cost overview (Appendix A) shows external transport costs are € 1,214,478.-. KD completely uses Hessenpoort and Staphorst, so SLN pays the full rent. Internal transport costs add up to 209,928.-.

Between locations transport (Appendix A)	€ 1,214,478.-
Rent Costs (Cost overview Scania solution 1)	€ 665,000.-
Internal transport costs (Cost overview Scania solution 1)	€ 209,928.-
	€ 2,089,406.-

7.2.2 Planned situation: KD costs 1,995,435

The cost overview (Appendix A) shows the current external transport costs are € 1,201,561.-. Hessenpoort and Staphorst are partly occupied by the Zwolle Boxes, so SLN pays less rent. Internal transport costs for KD activities add up to € 209,928.-.

Between locations transport (Appendix A)	€ 1,201,561.-
Rent Costs (Cost overview Scania solution 1)	€ 540,000.-
Internal transport costs (Cost overview Scania solution 1)	€ 253,874.-
	€ 1,995,435.-

The costs for the Zwolle Boxes are:

Between locations transport (Appendix A)	€ 278,333.-
Rent Costs (Cost overview Scania solution 1)	€ 125,000.-
Internal transport costs (Cost overview Scania solution 1)	€ 26,010.-
	€ 429,080.-

7.3 Scenario I: No Zwolle Boxes. Costs € 1,890,989.-

This section treats Scenario I, which does not consider the Zwolle Boxes and uses Hessenpoort and Staphorst as facilities. Subsection 7.3.1 treats the between locations costs and layout. Subsections 7.3.2 and 7.3.3 treat the facility level layouts at Staphorst and Hessenpoort and Subsection 7.3.4 treats the cost level implications of Scenario I.

7.3.1 System level: AUS to Hessenpoort is 11.8% cheaper

The only current transport between Hessenpoort and Staphorst is *From the reserve areas to AUS Picking*. Our simulation yields SLN requires at least 3 trucks to transport AUS at 36 trucks/day. To minimize external transport, SLN has to group all order pick processes in one facility. The activities together require (see Chapter 6) ca. 5550 m².

This would mean both facilities provide sufficient capacity, but Staphorst is lower than Hessenpoort and cannot house all activities. We choose to place them at Hessenpoort, also because except for AUS Picking all order pick activities are already there. Total transport costs for this scenario and our choices are € 1,071,736.- (Seer for a detailed overview Appendix A). Recall current external transport costs are € 1,214,478.-/year. Hence, our proposal lowers external transport costs with 11.8%.

7.3.2 Hessenpoort: Internal material handling costs € 106.535.-/year

To find layouts, our procedure first applies MULTIPLE and then CRAFT (Appendix B gives a step-by-step method overview). MULTIPLE only considers the workstation capacity requirements as constraint, executes Simulated Annealing and gives a solution top 10. First, we do not consider feasibility. In later steps we remove infeasible options and generate feasible good starting input for CRAFT. The top 10 MULTIPLE solutions has 3 common characteristics:

1. AUS pack/send is in Hall 4 (About completely fills the hall)
2. The pallet reserve area is in the above part of Hall 1.
3. AUS pick is in Hall 3,

The Output mostly contains unfeasible department shapes for AUS Picking. We consider two general feasible options as Figures 7.2 and 7.3 depict. We optimize for both options and choose the best one. We find two general "good" solution possibilities (Figures 7.2 and 7.3).

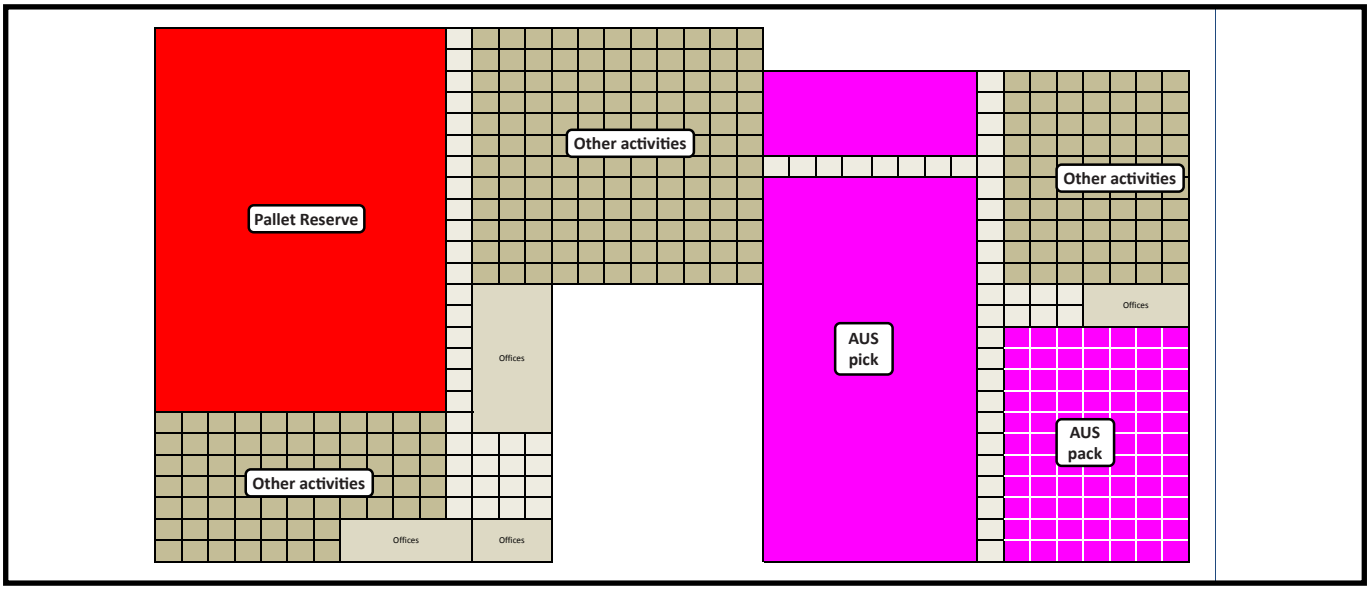


Figure 7.4 Option I

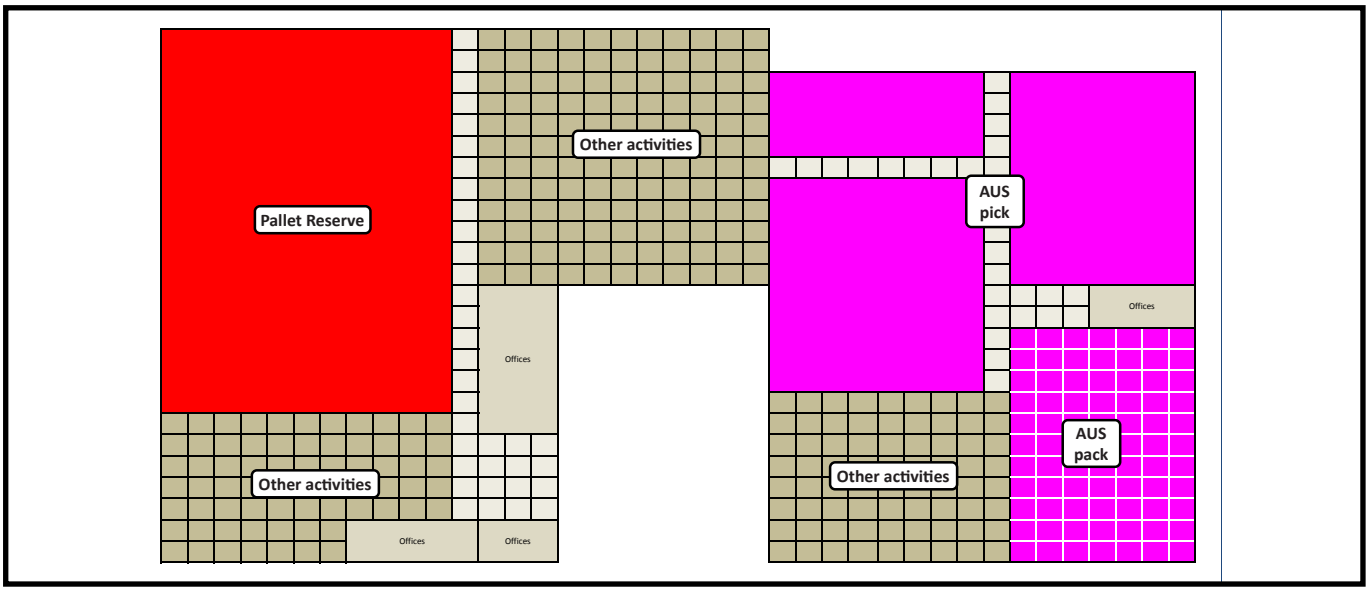


Figure 7.5 Option II

Our CRAFT procedure executes 2/3 departments exchanges to attain new solutions. Given a starting solution, it for each step defines exchange alternatives and measures their effects on the goal function value. If it finds an improvement, it continues and performs another iteration with the best alternative as starting solution. If not, the procedure terminates and the current solution is the final one. This method yields two layout alternatives:
We choose proposal I, because of:

- Lower expected internal travelling costs
- Reserve areas are grouped together
- AUS pick has a square shape

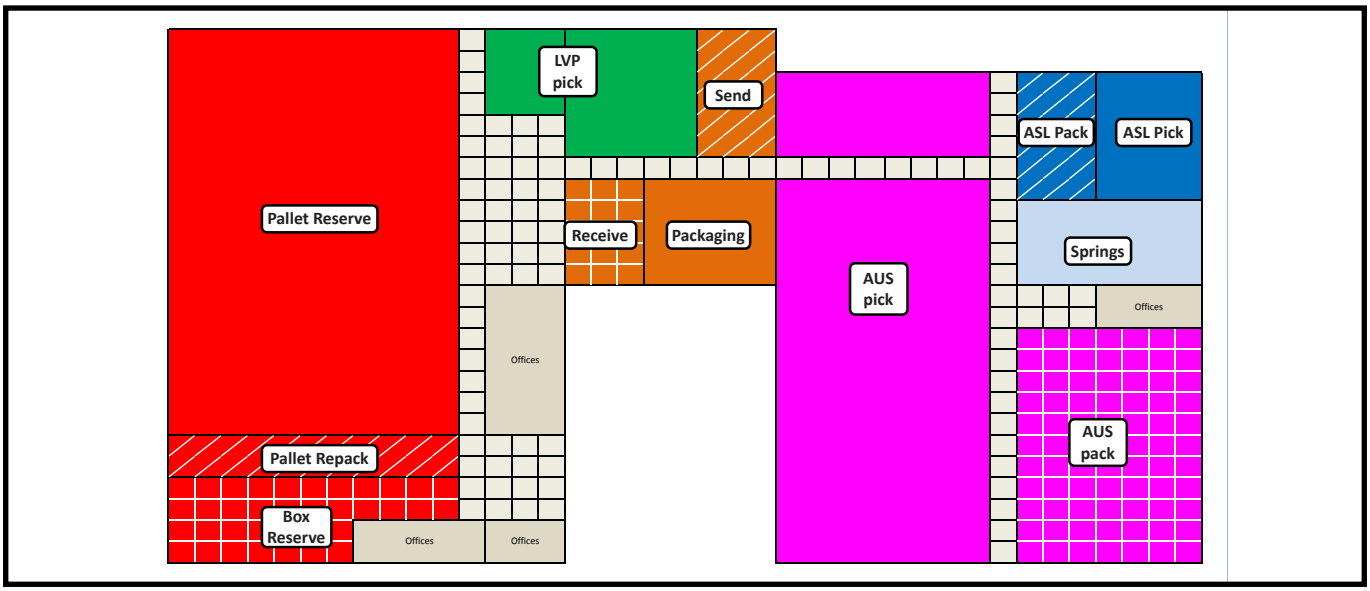


Figure 7.6 Layout Proposal I, relevant costs € 106.535.-/year

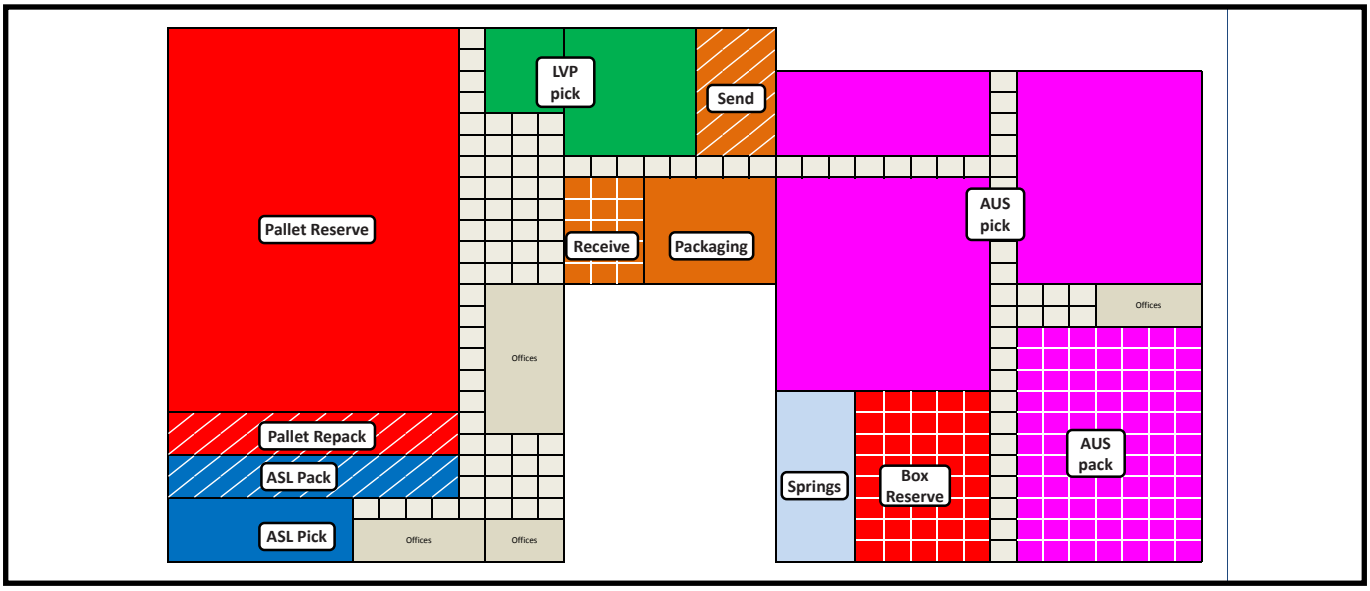


Figure 7.7 Layout Proposal II, relevant costs € 113.992.-/year

7.3.3 Staphorst: Internal material handling costs € 47,718.-/year

The amount of required Staphorst capacity is:

External Sequence	700 m²
Main Flow	650 m²
Packaging	50 m²
	1400 m²

This fits in 1 or 2 halls, we use Hall 1 and hall 3, since they have entrances. This keeps stations close to outside. Appendix C describes in more detail our procedure for Staphorst, which yields the following layout (Figure 7.8), which costs € 47,718.-/year. It seems logical since each cluster (Main Flows functions, Sequence functions) is in one hall and packaging is next to the External Sequence cluster, with whom it has most connections and it is to the side of the Main Flow cluster.

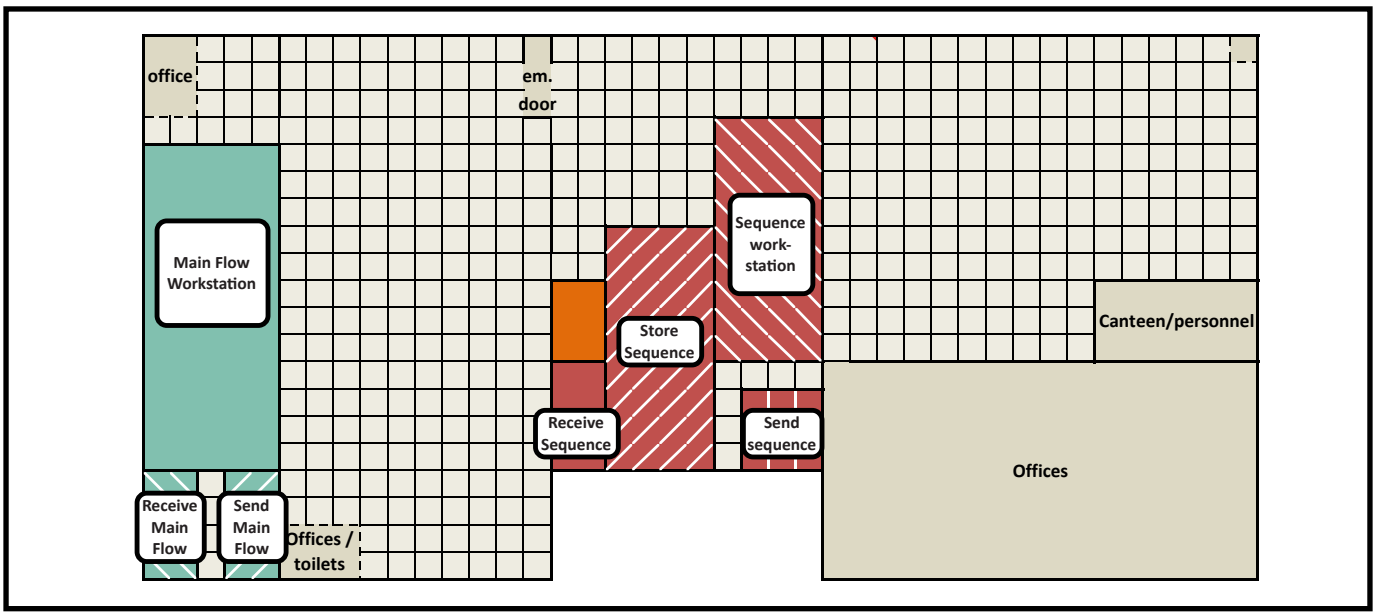


Figure 7.8 Staphorst scenario I, layout 1

7.3.4 Total costs Scenario I: Savings on external transport and internal handling

The costs of Scenario I are as follows:

Between locations transport (Appendix A)	€ 1,071,736.-
Rent Costs (Cost overview Scania solution 1)	€ 665,000.-
Internal transport costs (Cost overview Scania solution 1)	€ 154,253.-
	€ 1,890,989.-

The current costs are € 2,089,406.-, so Scenario I reduces costs with 9.5%. SLN still pays the full rent since no activities fill the now-free capacity. New activities can further reduce capacity costs. Internal handling lowers over a quarter and system level costs over 10%.

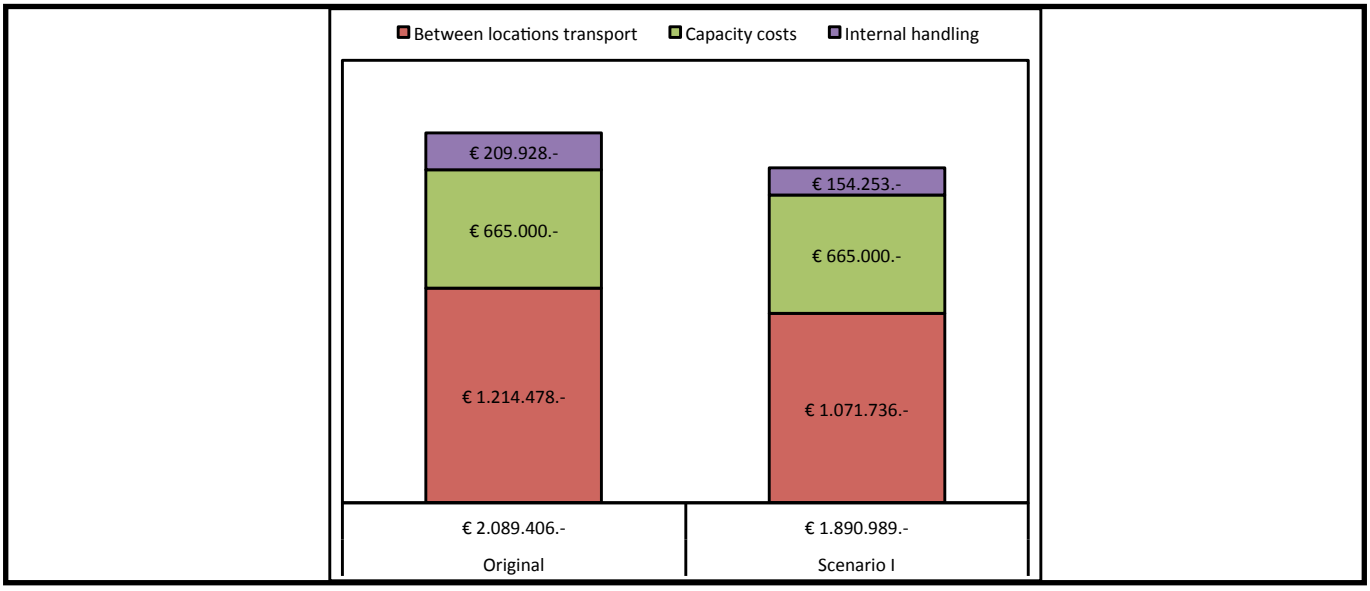


Figure 7.9 Performance measures Scenario I compared to Current Situation

7.4 Layout Scenario II- Including Zwolle Boxes. Costs € 1,711,989.-/year

This section treats Scenario II, which adds the Zwolle boxes to Scenario I and again uses Hessenpoort and Staphorst as facilities. Subsection 7.4.1 treats the between locations costs and layout. Subsections 7.4.2 and 7.4.3 treat the facility level layouts at Staphorst and Hessenpoort and Subsection 7.4.4 treats the Scenario II costs.

7.4.1 System level: Scania's plans and an alternative

Recall the Zwolle Boxes will move to Hessenpoort. This would mean all order pick operations do not fit in Hessenpoort together and AUS Picking has to stay in Staphorst, the AUS transports would remain. An alternative is placing the boxes at Staphorst. The ride Zwolle-Staphorst takes 22 minutes, while Zwolle-Hessenpoort takes 11 minutes.

SLN can trade off box travels vs. keeping the AUS transports. Appendix D calculates both alternatives. KD transports yearly costs are € 1,201,561.- for Scania's plan and € 1,071,736.- for our scenario. Hence, our scenario saves 10.8% of between-locations transport costs. This is excluding possible internal savings. (Total transport costs only decrease a little in our scenario, this does not matter a lot, since boxes are a temporary function at SLN).

7.4.2 Hessenpoort, same layout: Handling costs € 106,535.-/year

Hessenpoort has the same functions as in Scenario I. Therefore the same layout and cost apply.

7.4.3 Staphorst: Handling costs €107,125.-/year

Appendix D extensively presents our procedure. The best MULTIPLE options all have Zwolle Boxes in and around Hall 2. The function requires 1700 m², which fits in Hall 2. We fix it there and combine the other box processes with the final Scenario I Staphorst layout.

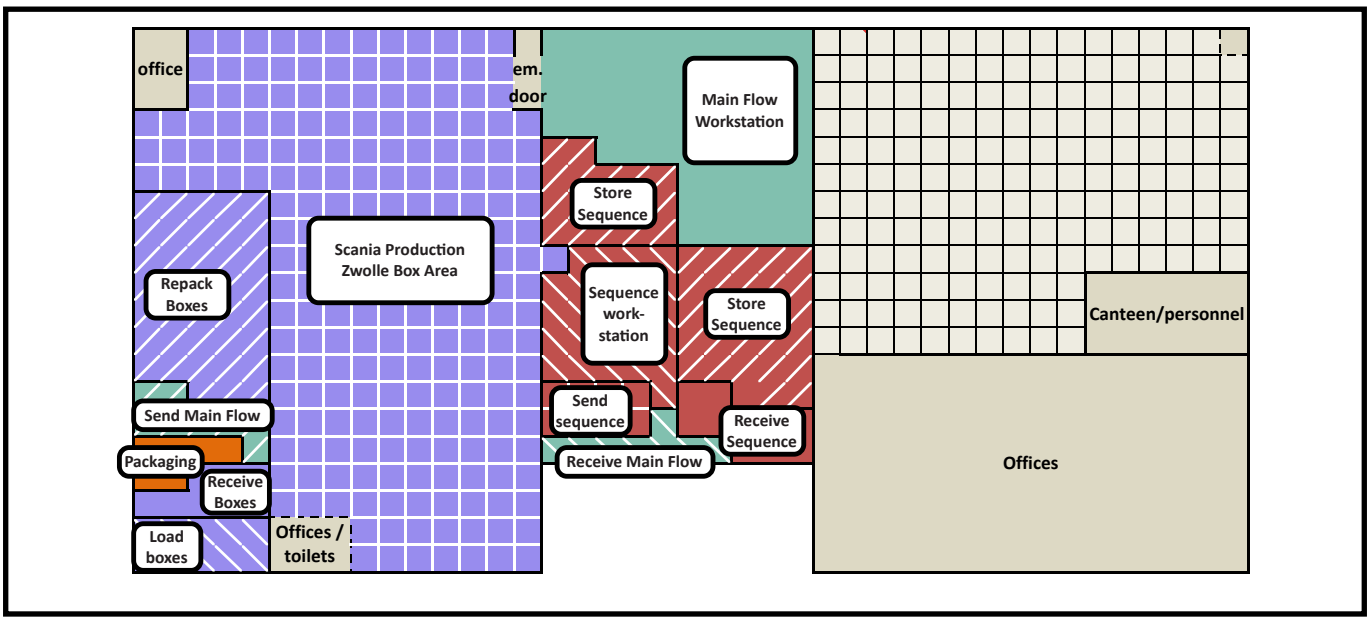


Figure 7.10 Example of MULTIPLE output

The final solution is found in 4 iterations:

Iteration	Goal function value
1	€ 111,126.-
2	€ 108,592.-
3	€ 107,184.-
4	€ 107,125.-

Table 7.1 CRAFT iterations Staphorst Scenario II

Total costs

Internal Staphorst transportation costs are € 107,125.-.

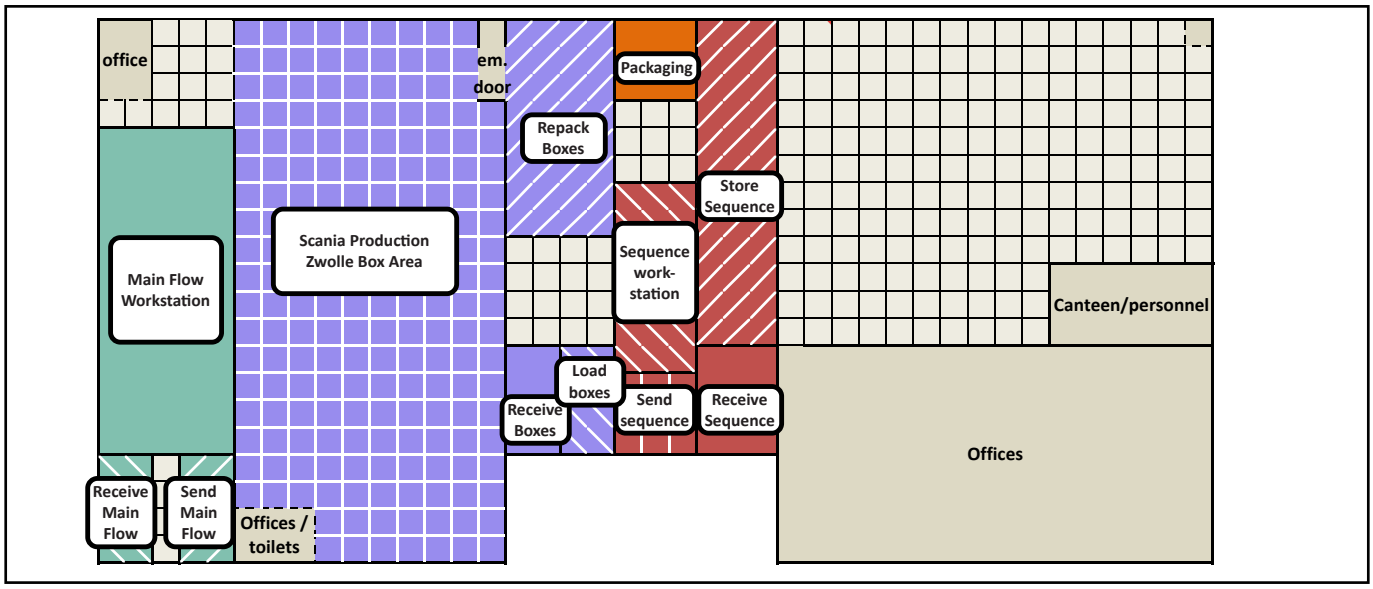


Figure 7.11 Final Staphorst layout with goal function value € 107,125.-/year

7.4.4 Scenario II costs: savings on external transport & internal handling

The costs of Scenario II are as follows. For KD:

Between locations transport (Appendix A)	€ 1,071,736.-
Rent Costs (Cost overview Scania solution 1)	€ 540,000.-
Internal transport costs (Cost overview Scania solution 1)	€ 175,000.-
	€ 1,787,697.-

And for the Zwolle Boxes:

Between locations transport (Appendix A)	€ 376,740.-
Rent Costs (Cost overview Scania solution 1)	€ 125,000.-
Internal transport costs (Cost overview Scania solution 1)	€ 37,699.-
	€ 539,439.-

Compared to Scania's plans, KD costs drop € 207,738.- and Boxes costs rise with € 110,359.-. Compared to Scania's plans, Scenario II uses less capacity. The KD savings consist of External Transports and Internal Handling, mainly caused by placing AUS Picking in Hessenpoort. This scenario also has leftover capacity, which SLN/KD still has to pay.

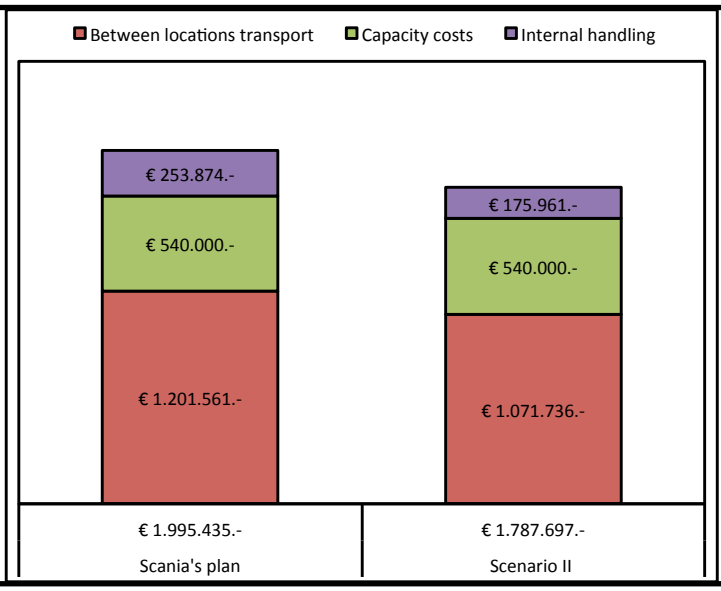


Figure 7.12 Performance measures Scenario II compared to Scania's plans

7.5 Scenario III Green field

This section treats Scenario III, which adds no functions and uses a Green Field facility instead of Staphorst and Hessenpoort. Subsection 7.5.1 reviews the system level effects, Subsection 7.5.2 determines the facility level layout and Subsection 7.5.3 treats the cost implications of this scenario.

7.5.1 System level

Scenario III has one facility. At 36 trucks/day, ca. 60 transports go to/from Scania Production Zwolle and ca. 30 go to/from Seacon. This facility has no location as yet. Since the number of transports to/from Zwolle is twice as high, it is logical to place the facility as close as possible to Zwolle. Zwolle itself has four industrial areas:

Facility	Truck Travel time Seacon	Truck travel time Scania Production Zwolle	Total travel time
Hessenpoort	24 minutes	11 minutes	1440 minutes
Vrolijkheid	27 minutes	9 minutes	1350 minutes
Marslanden	32 minutes	10 minutes	1560 minutes
Voorst	29 minutes	5 minutes	1170 minutes

Table 7.2 Zwolle industrial areas and resulting travel times

Voorst, where Scania Production Zwolle is located offers the best total travel time. Marslanden, the worst option has a total travel time of 1560 minutes, which is 33% higher. For the sake of this scenario, we assume the location of the facility is Hessenpoort (An in-between value). Appendix A shows total system level costs for this scenario and our choices are € 1.398.674.-/year. (Other industrial areas yield lower/higher results)

7.5.2 Facility level

On the facility level we again first apply MULTIPLE and then CRAFT. We assume:

- We use one central Receiving area, one central load area and one central packaging area. We assume all streams go in/out the facility via these areas.
- The minimum required capacity is 9353 m2, but we use more capacity: 11,600 m2. We expect loosening this constraint will benefit finding good MULTIPLE solutions. Later on, in the CRAFT procedure we seize upon

opportunities to reduce the occupied floor capacity.

- The applied parameters for the Simulated Annealing algorithm were:

Start temperature:	20
Cooling parameter:	0.999
Stop temperature:	0.5
Chain length	1000

Running time ca. half an hour.

The multiple output looks as follows:

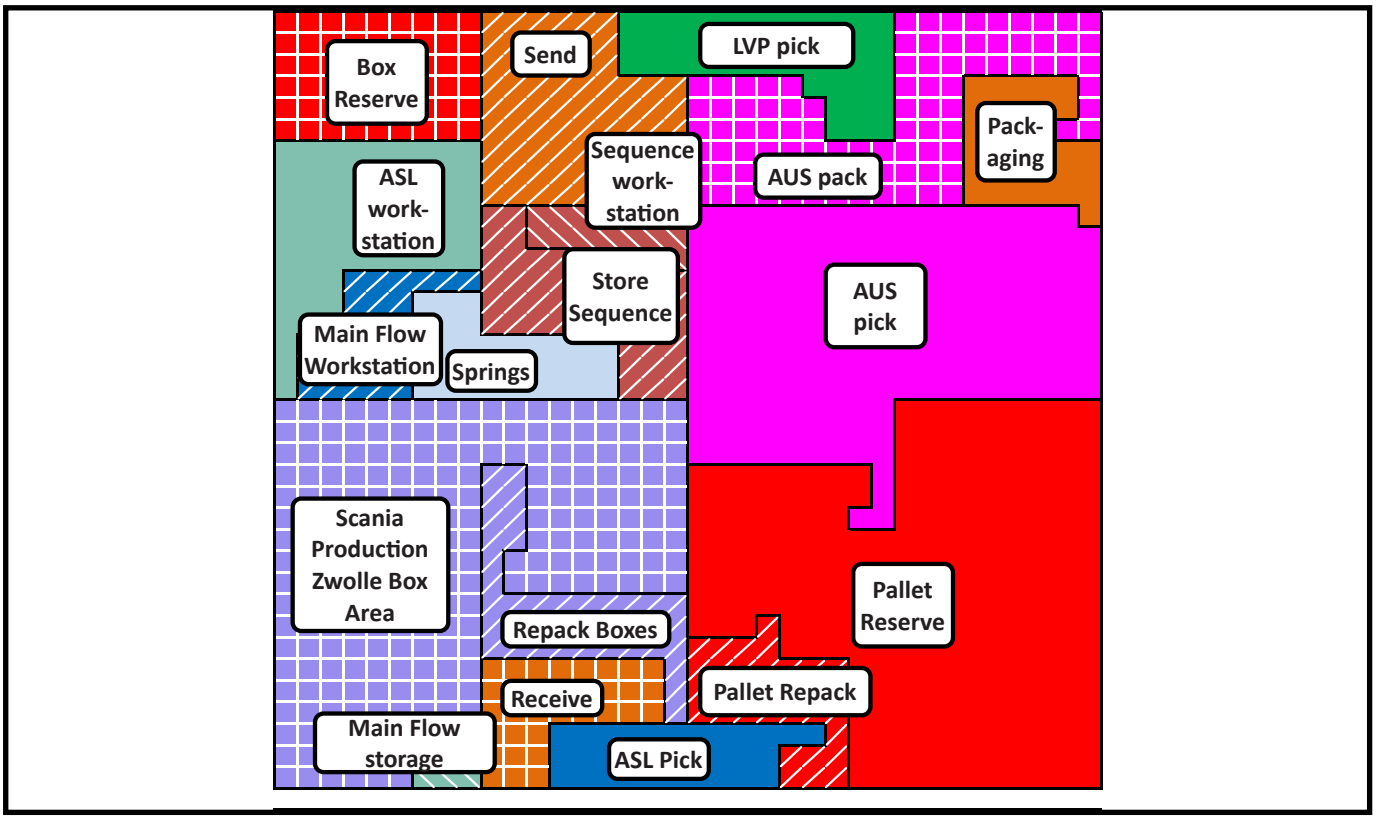


Figure 7.13 Best found MULTIPLE solution. Expected costs are € 268,218.-/year

We transpose MULTIPLE output to a feasible solution, which we use as CRAFT-input. This solution improves upon the MUTLIPLE solution and has expected costs of € 221,251.-. Our MULTIPLE procedure (Appendix F gives more details) has 6 iterations and the final solution has a goal function value of € 212,495.-.

Iteration	Goal function value
1	€ 221,251.-
2	€ 217,561.-
3	€ 216,083.-
4	€ 215,380.-
5	€ 212,598.-
6	€ 212,495.-

Table 7.3 CRAFT iterations Scenario III

The final green field layout uses 10,395 m2 of floor capacity. The current rent is ca. € 50.-/m2 a year. Then total rent is € 519,750.-.

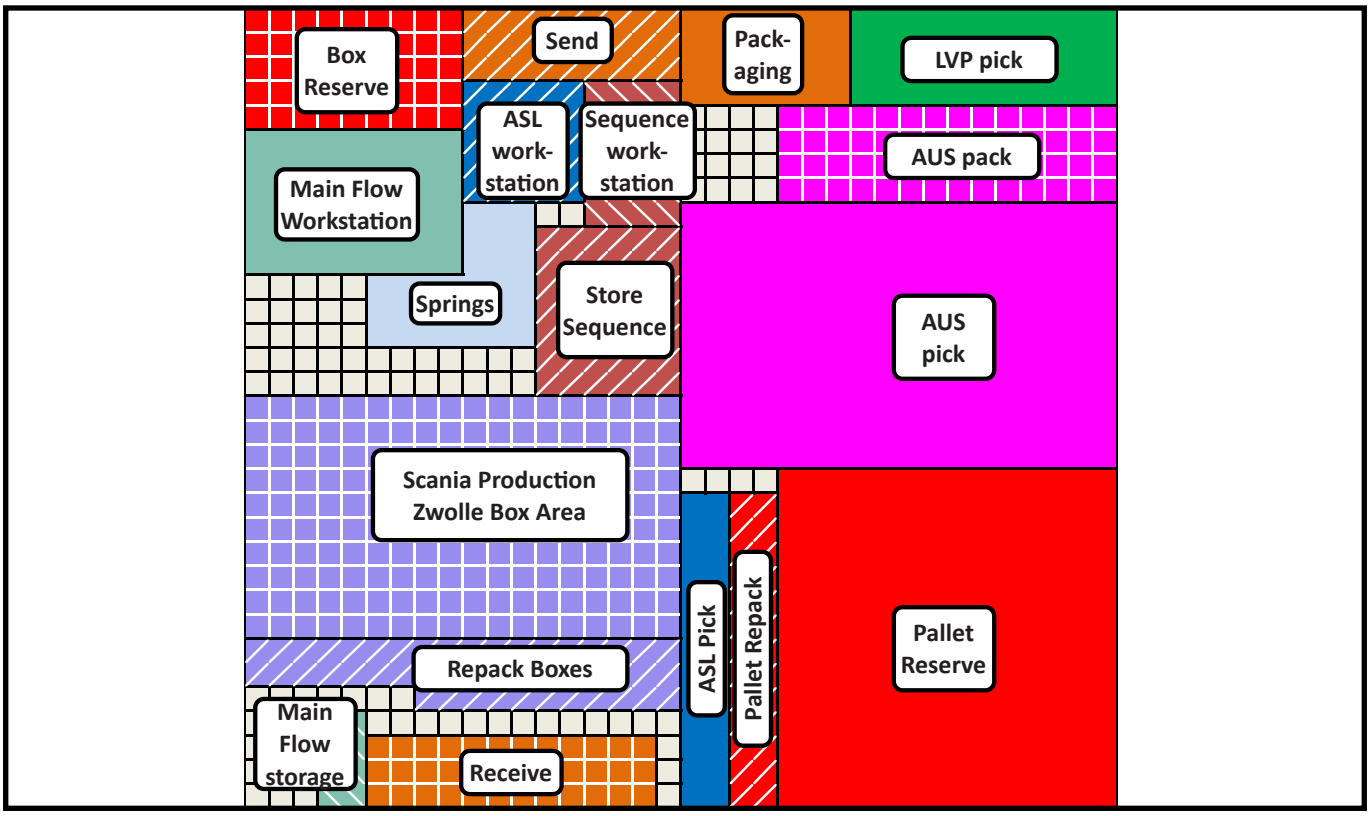


Figure 7.14 Layout proposal 1 with expected costs € 221.251/year

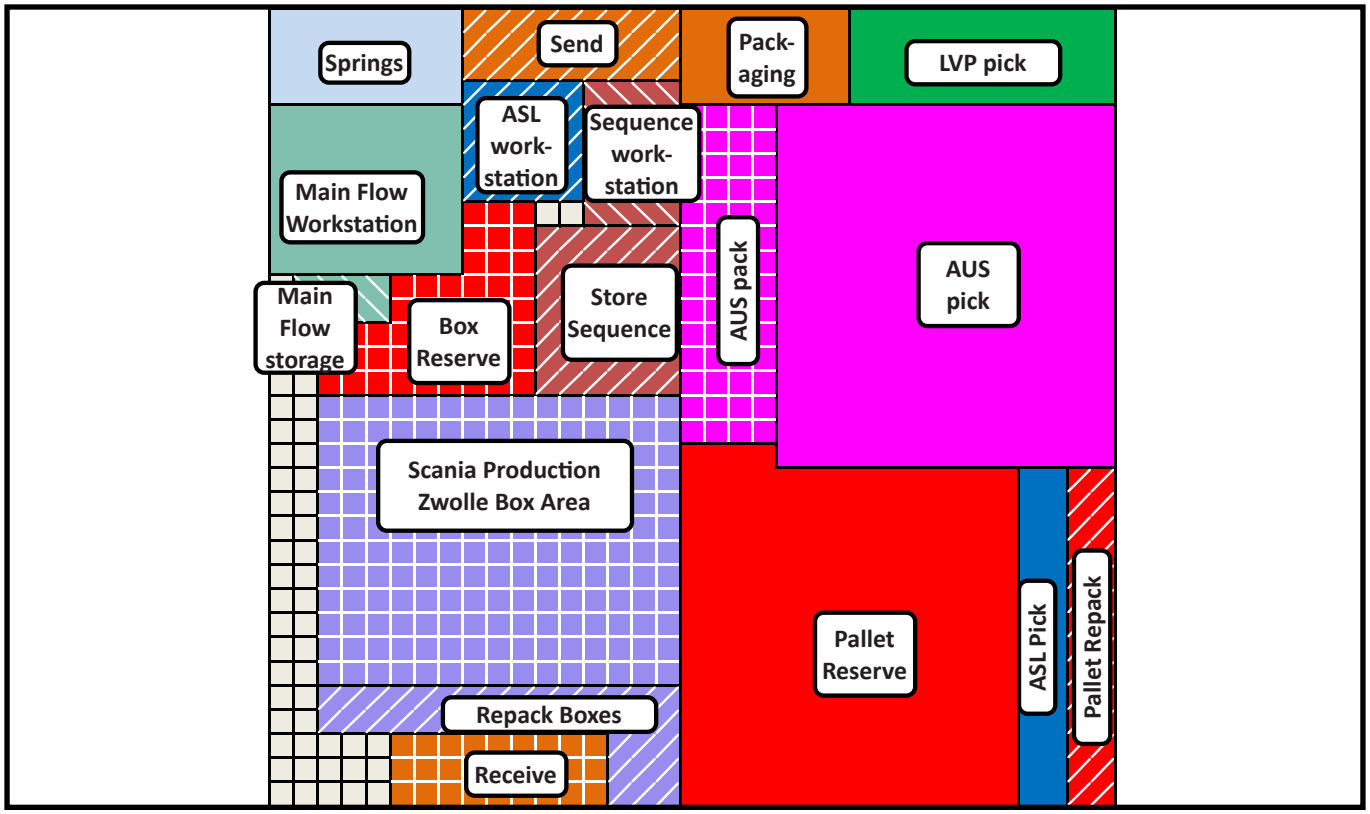


Figure 7.15 Final Layout (Unused capacity cut-away) with expected costs € 221.251/year

7.5.3 Scenario III costs: Savings on capacity & internal handling

The Scenario III costs are as follows. For KD:

Between locations transport (Appendix A)	€ 1,138,520.-
Rent Costs (Cost overview Scania solution 1)	€ 394,750.-
Internal transport costs (Cost overview Scania solution 1)	€ 164,601.-
	€ 1,698.131.-

And for the Zwolle Boxes:

Between locations transport (Appendix A)	€ 278,070.-
Rent Costs (Cost overview Scania solution 1)	€ 124,740.-
Internal transport costs (Cost overview Scania solution 1)	€ 47,858.-
	€ 450,668.-

KD costs decrease 6% compared to Scenario II and Boxes costs drop 16.4 %. Compared to Scania's plans, KD costs drop 15.8 %, while boxes costs rise with 5.1%. The KD cost decrease is mainly caused by a decreased capacity-usage. Internal handling costs have a lower decrease, but a decrease still seems an achievement, given 27% less capacity.

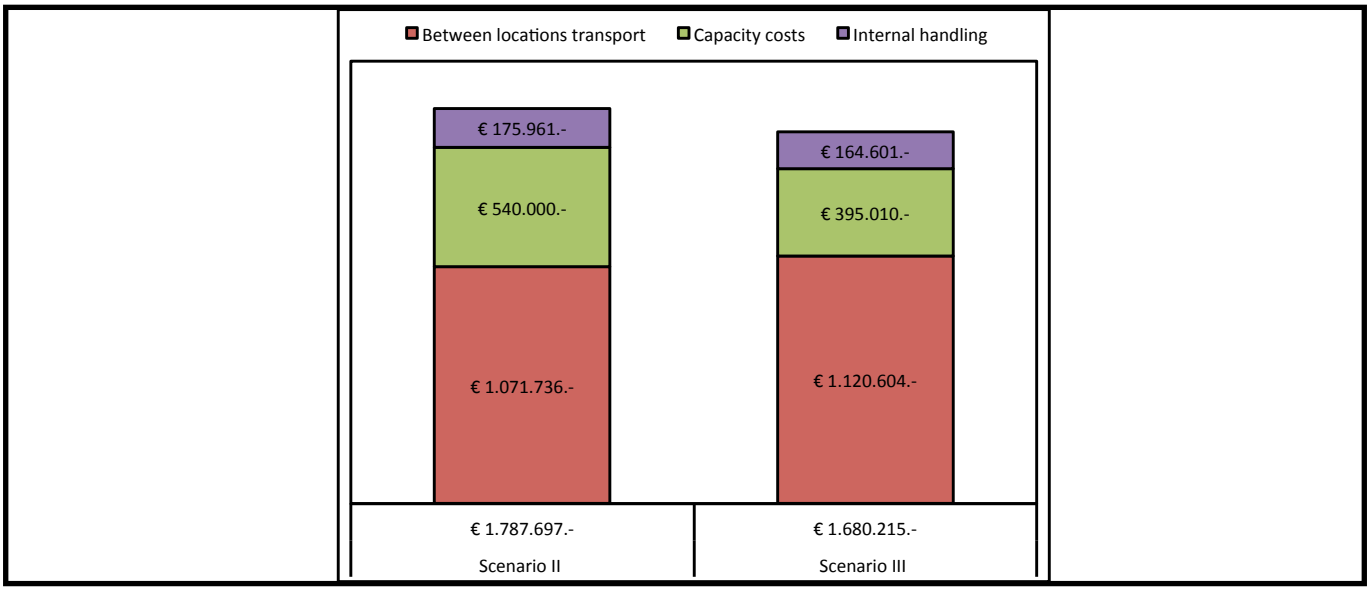


Figure 7.16 Performance measures Scenario III compared to Scenario II

7.6 Practical recommendations

Sections 7.3-7.5 create theoretical solutions, but the current situation imposes constraints, mainly since changing layouts costs money. Section 7.6 takes elements from the above solutions that can contribute to the current layouts and determines the costs of these concrete recommendations and estimates the associated costs.

7.6.1 Payback time: 3 years for KD in Staphorst/Hessenpoort & 1.5 years for the Zwolle Boxes

As mentioned before, SLN is a young, rapidly changing company. Payback times of years are infeasible, we consider payback times for the current facilities and for the Zwolle Boxes.

Hessenpoort and Staphorst are temporary solutions, but no one knows when one or more facilities replace them. Scania employees/managers mention various timeframes for this exchange. We note:

- Relocation plans do not seem concrete yet.
- Preparing and building new facilities consumes a considerable amount of time.
- Scania is still investing in the current facilities, indicating no hurry to relocate.

Considering the above, we assume three years of payback time for Hessenpoort and Staphorst. The managers we spoke reinforced this.

The Zwolle Boxes remain at SLN for ca. 1½ years. So in costs functions we only account for that time.

7.6.2 Low hanging fruits-

Our first range of recommendations covers the "Low hanging fruits". These are recommendations that cause little "pain", but usually provide little gains/savings.

Fill Pallet Reserve Area from the other side- Savings of € 2700.-/metre

Chapter 3 mentions SLN fills the Pallet Reserve Area from the side opposite from the loading docks. Our layout tools shows that each metre the storage area's midpoint moves towards the docks saves € 900.-/year. Considering the three years payback time, total savings are €2700.-/metre.

Filling as much as possible from the other side means the midpoint can shift several metres. In the storages areas, locations have various characteristics- pallets do not fit in each location. This adds restrictions to the effectiveness of this recommendation. Solving this restriction requires considerable investments (for changing the physical racks), so the high hanging fruits include further recommendations, which require larger investments.

Place LVP Picking in the left part of Hall 2/right part of Hall 1 at Hessenpoort Savings of € 13,500.-

Placing LVP Picking in Hall 1 and Hall 2 means placing it in the line of the current flow and reducing total material handling. Our tool shows costs drop with € 4500.-/year. With a three years payback that is € 13,500.- in total. LVP Picking has flexible, lightweight racks; relocating them does not imply large costs. In addition, LVP remains in Hessenpoort, so this causes no transportation costs.

7.6.3 Middle fruits

Replace Kanban for AUS and ASL- Capacity savings of € 330.000.-

Again, we propose removing kanban and letting reserve areas deliver to ASL/AUS pick areas based on present-day demand. In total, this spares 2200 m² of capacity. Assuming the previous mentioned yearly price of € 50.-/m², the capacity savings amount to € 110.000/year. Considering the 3 years payback, total savings are € 330,000.-. In addition, a) stock levels will significantly drop and b) the average distances to/from the pick areas will drop. As (a) is out of scope and (b) is hard to quantify, we only directly account for capacity savings.

SLN is working on a "free location system", which amongst others facilitates the above-mentioned removal of Kanban. The ERP system change request is scheduled to be implemented in December, which means from then on the system allow free locations.

Place AUS at Hessenpoort and the Zwolle Boxes at Staphorst

Scenarios I & II recommend placing AUS Picking with reduced capacity in Hessenpoort. The decision to place the Zwolle Boxes at Hessenpoort is already made and the preparations to accomplish this are well underway. If Scania can take a turn and can still place AUS Picking in Hessenpoort and the Zwolle Boxes in Staphorst, they can still save money. The above recommendation- removal of Kanban is a condition for this, since capacity usage has to drop.

No AUS transport	€ 78.- × 5/day × (½ h loading+11/60 h driving+ ½ h unloading + 11/60 h driving) *230 workdays * 3 years = € 367,770.-
Extra distance for boxes	€ 78.- * 11/60 hours * 30 rides * 230 working days * 1.5 years = € 148,005.-
Assembly/disassembly	€ 62,500.-
Other building costs	€ 50,000.-

Table 7.4 Cost overview AUS Picking at Hessenpoort & Zwolle Boxes at Staphorst

Costs and gains We do not have a case for AUS, but we can use quotations for the Zwolle Boxes area. Scania pays ca. € 28,500.- for assembling the storage racks at Hessenpoort. The area has ca. 2000 locations. To get a cost estimation for AUS Picking, we assume Scania pays the moving per storage location.

Chapter 6 assesses Aus Picking needs 2200 (10% more than the boxes) locations after the removal of kanban. So we estimate assembly costs are 10% higher: € 31,250.-. We did not find a case for disassembly of storage racks, but since disassembly roughly has the same operations as assembly (in reversed sequence), we assume disassembly has the same costs. So we assume moving AUS costs ca. € 62.500,-

In addition €50.000 is reserved for "other building costs". Scania engineers made clear they often face unexpected costs for large projects. Their expert opinion yields € 50,000.- as expected additional costs. Those costs might not exist or might be higher, but we account for them to provide a scenario as realistic as possible.

Then SLN can gain € 107,265.-. Assembly/disassembly/other building costs for the Zwolle Boxes are somewhat lower. This means this recommendation is not worthwhile if Scania has already placed the Zwolle Boxes at Hesenpoort. This means if Scania cannot turn its plan around, then they should not follow up this recommendation.

Soft advantages In addition to financial advantages, Scania can gain 'soft' advantages. The order pick parts are all related and having them at a single facility clusters all SLN picking experience/knowledge, simplifies processes such as job rotation (higher flexible employees, since processes are more alike) and creates a shorter lead time for order pick parts.

Implementation AUS Picking is still too large to fit in Hessenpoort, so we advice a face-out. Let Hall 2 in Staphorst go empty, while maintaining the picking in Hall 4. Move the Hall 2 AUS storage racks to Hessenpoort and the Zwolle Boxes to Staphorst. SLN could then temporarily contain two picking areas. When the ERP system is ready, SLN can phase out the Staphorst storage.

Send full material units, up to 50.8% savings in flows and storage locations

The Order Pick Simulation tests the effects of sending as many as possible full AUS/LVP material units to Seacon. Given the simulation output (Figure 5.7) the percentages of material units that SLN can send to Seacon without a forward area and associated material flows:

Material unit\Part type	#AUS	%AUS	#LVP	%LVP
Pallets	73/467	15.6 %	-	-
Boxes	54/242	22.3 %	1/36	04.5 %
Inner-units	15/336	04.5 %	322/634	50.8 %

Table 7.5 Percentages that can be sent directly

This shows this method can be useful. Each part sent directly to the send area/Seacon, does not go to through the picking areas. This saves material flows and order pick capacity; since each part that bypasses picking does not have

any duration there. These outcomes also reinforce SLN in their plans and experiments to send full units.

7.6.4 High hanging fruits

Update/ replace the ERP system- Savings unknown
Material handling changes strongly impact the ERP system in terms of manual handling and Chapter 3 mentions the system is rigid. We recommend Scania to at least for warehousing operations, update the system or to acquire a new system. In a rapidly changing environment, information systems should provide high flexibility and fast handling of changes, instead of being a major restriction.

The ERP system is outside our scope and our recommendation is a strategic decision and would require large investments in both money and time. We however see this project already experiences various information system restrictions to layout optimization.

Zoning in reserve-/forward areas- Savings unknown
Our advice to fill the reserve area from the other side reduces average material flow distances. Zoning can further reduce these distances. E.g., the following zoning could reduce material flows for the pallet reserve area.

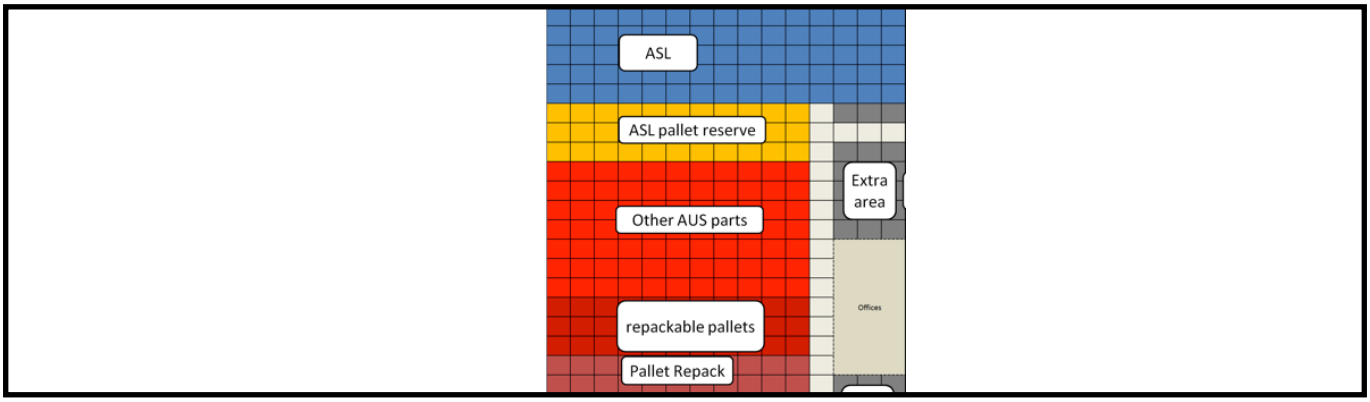


Figure 7.17 Hessenpoort Hall 1 with a possible zoning

Take Figure 7.18, the only current flows going downwards (in the figure), are pallets going to the pallet repack. It stands to reason to create a zone in the lower part of the reserve area for these re-packable pallets, so that pallets only have to travel far if they have to travel further into Hall 1 later on. This way, other parts have a higher midpoint, which reduces their travel distances. Likewise, placing ASL pallets close to the ASL area likely reduces travel distances.

There is an issue to this; the physical building of the storage areas however is constructed to support the current part division in the storage. To effectively apply zoning, the physical building needs to support the pallet-type in that zone. Rebuilding the storage area may thus be required. Such operations often cost several thousands of euros and it is questionable if the associated savings can guarantee a reasonable payback time.

7.6.5 Other recommendations

The chapter first analyses 2 'current'-situation and 3 scenarios to feasible and profitable change options. The following observations can be made:

- The largest cost post, between locations transport costs seems to be relatively inflexible. Scania Production Zwolle and Seacon in Meppel are both in contact with the SLN facility/facilities. This study assumes both locations given, but to reduce these distances, SLN could consider alternative harbour locations or decrease the number of transports to other locations.

- This study shows two ways to reduce capacity costs:
  1. Building a smaller facility
  2. Reduce current capacity usage and fill leftover capacity with other (value adding) activities.
- This Chapter tested a Green Field Option. Total Costs turned out to be 6% lower than the optimal Scenario II option. This is again largely affected by the inflexible external transport costs. The Green Field necessity is amplified by the changing costs of the other options. We however see that during the execution of this study, SLN applied some large changes in activities. The question remains how many changes SLN will keep applying in the coming years, which is largely related to costs of change timing.

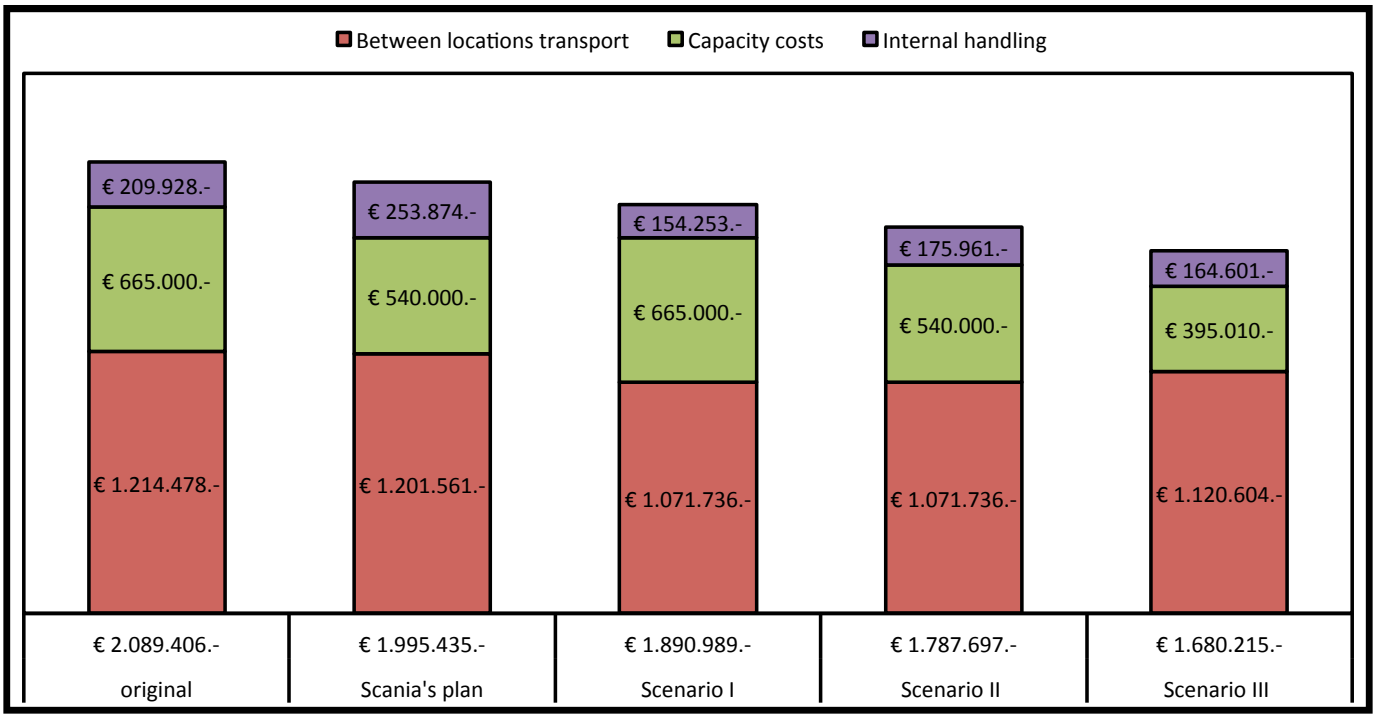


Figure 7.18 Total Cost Overview

7.7 Chapter conclusion

Chapter 7 answers Research Question 6:

"How can SLN redesign its layouts and how do the changes affect SLN's performance?"

The chapter finds that given the fixed locations SLN can reduce its operational KD costs up to 15.8%/€ 315,220.- (Green Field solution). In our scope, between-locations transport, which form over 50% of total cost, are relatively cost inelastic, since the locations and flows from/to Scania Production Zwolle and Seacon are fixed. Reducing these flow quantities or finding a closer harbour location could reduce this large cost post.

Section 7.7 transposes these theoretical layouts to practical recommendations on 3 levels: (1) low hanging fruits- easy to apply, low savings, (2)middle fruits- more effort to apply, more savings, (3) hard to apply, large savings (in our case unknown). The Green Field has some costs advantages, but to our opinion should be closely timed as Scania should avoid high costs of change.

Chapter 8 finishes this study by presenting our conclusions and recommendations. It present the direct lessons learned from this study and the factor more tangentially related to the study.

8. conclusions and recommendations

Chapter 8 is the study's final chapter and answers our Main Question:

"How can SLN redesign its layouts to reduce its material handling costs?"

Section 8.1 Concludes on this study and its outcomes and summarises the recommendations and potential gains. Section 8.2 comment on this study's methodology, which can help Scania to attain a standard approach to such problems. Finally, Section 8.3 gives recommendations for further research.

8.1 The layout redesign

All scenarios yield improvements to the current situation; Scenario III lowers Internal Handling costs with ca. 20% and Capacity costs with ca. 40%, but our scenarios are theoretical and changing costs make completely moving to these solutions expensive. This has two implications: It (1) increases the importance and gains of moving to the Green Field situation and (2) forces us not to stick with the theoretical layouts, but to extract from them lessons and practical/economic favourable recommendations. We list here the practical recommendations of Chapter 7.

Low hanging fruits

- Place LVP Picking in the left part of Hall 2/right part of Hall 1 at Hessenpoort
- Fill the pallet reserve area in Hessenpoort as much as possible from the docks' side

Middle fruits

- Discard kanban at picking areas and supply to these areas based on their short term demand
- Place AUS at Hessenpoort and the Zwolle Boxes at Staphorst
- Send as much as possible full material units

High hanging fruits

- Adapt the ERP system to be able to effectively handle warehousing decisions and handling
- Apply zoning to storage- and picking areas

These practical recommendations help SLN to reduce costs. Especially the middle and high hanging fruits contain larger, more elementary changes, which reduce handling, floor capacity requirements and flows. The Green Field situation is still attainable and the changing costs of the current facilities amplify its necessity. We however urge SLN to carefully plan the Green Field timing; if large changes in e.g. (exaction of)activities occur in the coming years, the situation might be too unstable for the Green Field facility. I.e. A Green Field situation can avoid large change costs and can create a reengineered process and large changes would counteract these effects.

8.2 Methodological guidelines

Not only does this study generate results concerning SLN's layouts, it also offers a structured facility layout approach. This section gives our layout solving structure and our orderpick simulation as methods/guidelines Scania can use or at least learn from.

8.2.1 A structured layout approach

This study offers Scania a structured approach to the facility layout problem which is on the one hand closely tied to the ideas and methods of Richard Muther, but also builds on this by applying new heuristics and methods.

The layout tool stands out as such an appliance; it first applies a combination of MULTIPLE and Simulated Annealing, which evaluates over a thousand layout options per second. The facility planner then transfers the layout to a sheet, where he/she determines the departmental midpoints and lets the tool calculate the goal function value. The planner exchanges various departments to easily find good solutions.

8.2.2 An Order Pick Simulation as a unique approach to flow determination & capacity setting

Our order pick Simulation offers, as far as we can find, a new approach to flow-determination and capacity setting for a layout problem. The simulation logic gives SLN more grip on its order pick processes and its storage areas. Advantages include:

- It is a collection of part information, which is unique to Scania.
- It is a visual way of describing material flows. This adds to the credibility towards users.
- It gives an over-time analysis of materials flows and capacities, allowing the user to work with averages, higher decimal values and see the long term effect of actions on order pick and storage areas.

In addition, scholars and practitioners alike can benefit from our simulation approach. It takes flow- and capacity analysis to a next level. It improves on analyses based on guesses and feeling. It also improves on numerical analyses, because such methods can consider e.g. long-term effects, variability and output behaviour.

8.3 Further research

This section gives recommendations regarding further research. These include recommendations directly and indirectly linked to this study.

A new harbour location

Chapter 7 shows between-locations transports strongly affects the total relevant costs. Even the Green Field scenario yields only a small improvement. This is because SLN has to service both Scania Production Zwolle and Seacon. We recommend Scania to research the gains of using a harbour location closer to Zwolle.

Shortening warehouse flows

This reports treats sending full units as a way to skip a warehouse flow (the forward area in this case). Additional methods exist to shorten or simplify these flows and SLN can benefit from researching such possibilities. Useful examples include kitting of parts that often/mostly appear together in certain trucks or planning supplier arrivals such that they can be directly cross-docked and thus skip both reserve and forward areas.

Configuration storage/reserve areas

One of our recommendations is for SLN to apply zoning in storage areas. SLN can apply several zoning groups/ divisions and should investigate which options are most profitable in terms of capacity requirement and material flow lengths.

Technological solutions

Section 8.3 notes Scania's restraint towards technological solutions (e.g. material handling equipment) and its need for improved throughput and efficient capacity usage. We believe one way to make changes in this area, is researching all effects of acquiring and using new solutions: i.e. the costs of equipment failure and the (financial) gains from increased throughput and more efficient capacity usage.

Inventory management

Most issues we faced such as storage capacity requirements, material rules have a connection to material/inventory management. Stock levels and reorder point seem to be important cost determiners and SLN can probably benefit from researching how it can benefit from inventory management- seeking a balance between service levels and costs.

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A. System level distance function

Appendix A displays for all scenario's the system level costs. Figure A.1 depicts the current situation, Figure A.2 the planned situation with the Zwolle Boxes, Figure A.3 Scenario I, Figure A.4 Scenario II and Figure A.5 Scenario III.

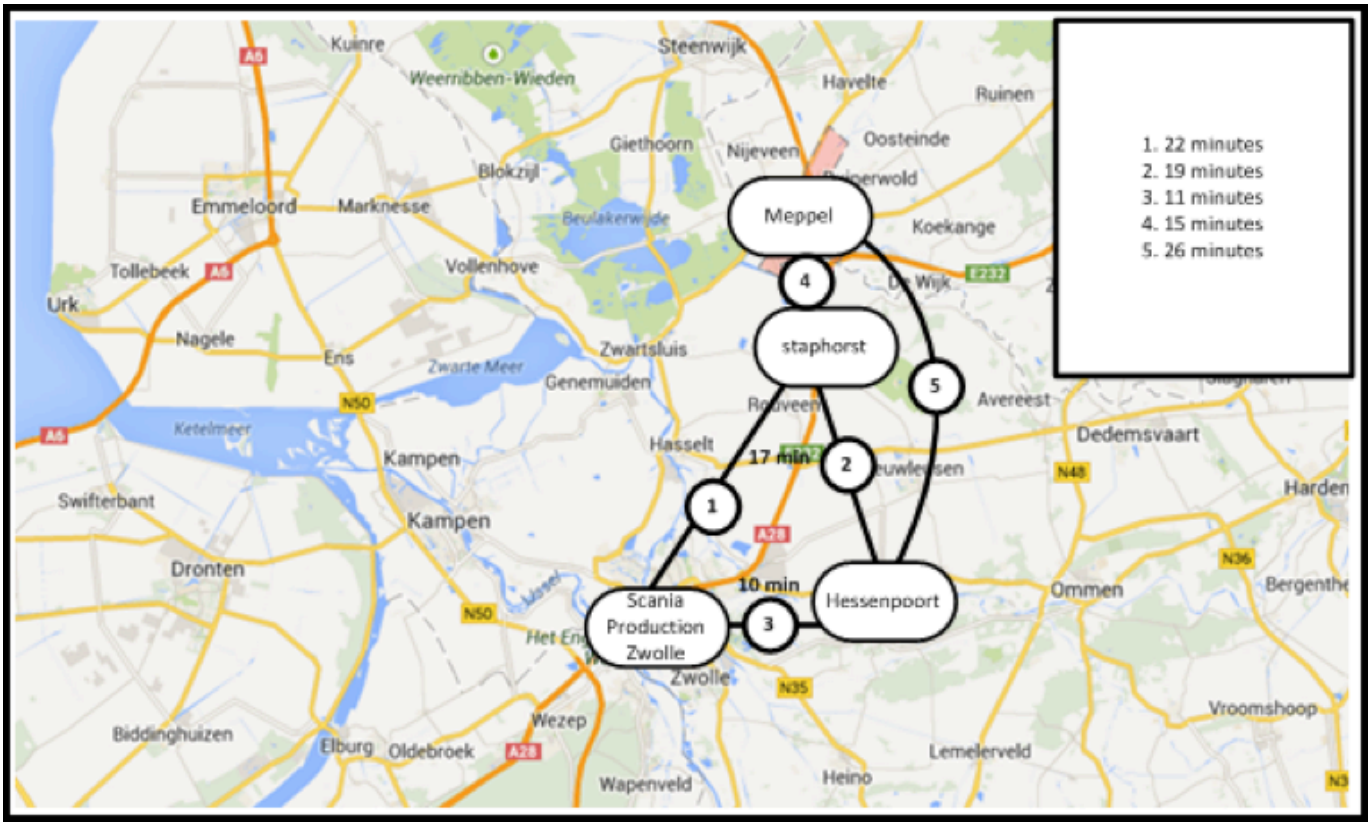

Figure A.1 System level map

A.1 Current layout- Excluding boxes

Travel						
What	from	to	Travel time	Load time	Unload time	Flow quantity (day)
Supplier to SLN	Scania production Zwolle	Hessenpoort	11	30	30	30
LVP to Seacon	Hessenpoort	Seacon	24	30	30	0,2
AUS to Staphorst	Hessenpoort	Staphorst	19	30	30	5
AUS to Seacon	Staphorst	Seacon	15	30	30	3,2
ASL to Seacon	Hessenpoort	Seacon	24	30	30	1,5
Springs to Seacon	Hessenpoort	Seacon	24	30	30	1
Sequence to Seacon	Staphorst	Seacon	15	30	30	4,8
Main Flow to Seacon	Staphorst	Seacon	15	30	30	4,3
Back to H'poort	Staphorst	Hessenpoort	19	0	0	5
Back to H'poort	Seacon	Hessenpoort	24	0	0	7,5
Back to Staphorst	Seacon	Staphorst	15	0	0	7,5
			4061,8	minutes		
			67,7	hours		

KD costs	€	5.280	Costs/day
KD costs	€	1.214.478	Costs/year

Figure A.2 System flows current situation

A.2 Planned layout- including boxes

Travel						
What	from	to	Travel time	Load time	Unload time	Flow quantity (day)
Boxes ride to Hessenpoort	Scania production	Hessenpoort	11	20	20	15,0
Ride back	Hessenpoort	Scania Production	11	0	0	15,0
Supplier to SLN	Scania production	Hessenpoort	11	30	30	30
LVP to Seacon	Hessenpoort	Seacon	24	30	30	0,2
AUS to Staphorst	Hessenpoort	Staphorst	19	30	30	5
AUS to Seacon	Staphorst	Seacon	15	30	30	3,2
ASL to Seacon	Hessenpoort	Seacon	24	30	30	1,5
Springs to Seacon	Hessenpoort	Seacon	24	30	30	1
Sequence to Seacon	Staphorst	Seacon	15	30	30	4,8
Main Flow to Seacon	Staphorst	Seacon	15	30	30	4,3
Back to H'poort	Staphorst	Hessenpoort	19	0	0	5
Back to H'poort	Seacon	Hessenpoort	24	0	0	2,7
Back to Staphorst	Seacon	Staphorst	15	0	0	12,3
			4948,6	minutes		
			82,5	hours		

Total costs	€ 6.433	Costs/day
Total costs	€ 1.479.631	Costs/year
KD costs	€ 5.224	Costs/day
KD costs	€ 1.201.561	Costs/year

Figure A.3 System flows planned situation

A.3 Scenario I

Travel						
What	from	to	Travel time	Load time	Unload time	Flow quantity (day)
Supplier to SLN	Scania production	Hessenpoort	11	30	30	30
LVP to Seacon	Hessenpoort	Seacon	24	30	30	0,2
AUS to Seacon	Hessenpoort	Seacon	24	30	30	3,2
ASL to Seacon	Hessenpoort	Seacon	24	30	30	1,5
Springs to Seacon	Hessenpoort	Seacon	24	30	30	1
Back to H'poort	Seacon	Hessenpoort	24	0	0	5,9
Sequence to Seacon	Staphorst	Seacon	15	30	30	4,78
Main Flow to Seacon	Staphorst	Seacon	15	30	30	4,3
Back to Staphorst	Seacon	Staphorst	15	0	0	9,08
			3584,4	minutes		
			59,7	hours		

KD costs	€ 4.660	Costs/day
KD costs	€ 1.071.736	Costs/year

Figure A.4 System flows Scenario I

A.4 Scenario II

Travel						
What	from	to	Travel time	Load time	Unload time	Flow quantity (day)
Boxes ride to Staphorst	Scania production	Staphorst	22	20	20	15,0
Ride back	Staphorst	Scania Production	22	0	0	15,0
Supplier to SLN	Scania production	Hessenpoort	11	30	30	30,0
LVP to Seacon	Hessenpoort	Seacon	24	30	30	0,2
AUS to Seacon	Hessenpoort	Seacon	24	30	30	3,2
ASL to Seacon	Hessenpoort	Seacon	24	30	30	1,5
Springs to Seacon	Hessenpoort	Seacon	24	30	30	1,0
Back to H'poort	Seacon	Hessenpoort	24	0	0	5,9
Sequence to Seacon	Staphorst	Seacon	15	30	30	4,8
Main Flow to Seacon	Staphorst	Seacon	15	30	30	4,3
Back to Staphorst	Seacon	Staphorst	15	0	0	9,1
			4844,4	minutes		
			80,7	hours		

Total costs	€ 6.298	Costs/day
Total costs	€ 1.448.476	Costs/year
KD costs	€ 4.660	Costs/day
KD costs	€ 1.071.736	Costs/year

Figure A.5 System flows Scenario II

A.5 Scenario III

Travel						
What	from	to	Travel time	Load time	Unload time	Flow quantity (day)
Box ride Scania Production Zwolle	Green Field	Scania Production Zwolle	11	20	20	15
Ride back from Seacon	Scania production Zwolle	Green Field	11	0	0	15
Supplier to SLN	Scania production Zwolle	Green Field	11	30	30	30
Parts to Seacon	Warehouse	Seacon	24	30	30	14,98
Ride back from Seacon	Warehouse	Seacon	24	0	0	14,98
			4677,84	minutes		
			78,0	hours		

Total costs	€ 6.081	Costs/day
Total costs	€ 1.398.674	Costs/year
KD costs	€ 4.872	Costs/day
KD costs	€ 1.120.604	Costs/year

Figure A.6 System flows Scenario III

B. Layout Hessenpoort in Scenarios II/III

To determine important factors for good solution, we perform a MULTIPLE run. Table C.1 displays the sequence of departments and Figure C.1 exemplifies how this looks like. We note that available capacity is larger than the required capacity. Therefore alterations of capacity are possible.

#	1	2	3	4	5	6	7	8	9	10	11	12	Cost/ day
146	6	4	9	8	3	1	10	5	12	2	7	11	€ 455.23
117	9	2	8	3	12	1	10	5	6	4	7	11	€ 456.29
87	8	6	4	9	3	1	10	5	12	2	7	11	€ 459.18
111	9	2	4	8	3	1	12	10	5	6	7	11	€ 459.46
111	9	2	4	8	3	1	12	10	5	6	7	11	€ 459.46
5	6	9	4	8	3	1	12	10	5	2	7	11	€ 461.06
88	8	2	9	3	12	1	10	5	4	6	7	11	€ 461.50
51	9	4	8	3	6	1	10	12	5	2	7	11	€ 461.56
61	8	2	4	9	3	1	10	5	12	6	7	11	€ 462.15
4	6	8	4	9	3	1	12	10	5	2	7	11	€ 462.46

Table B.1 Top 10 Hessenpoort solutions with MULTIPLE

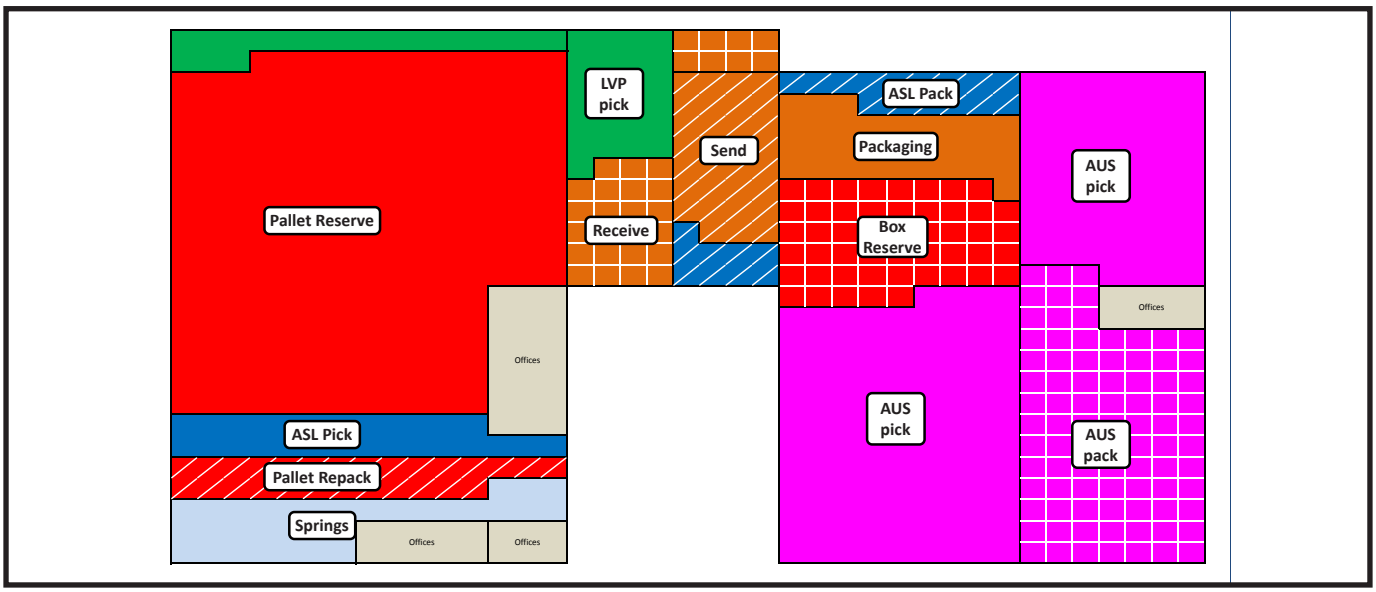

Figure B.1 Example of MULTIPLE output

We note that AUS pack is always located at Hall 4. We fix its location and reduce its capacity to exactly Hall 4 and plan the other departments according to this. Table C.2 depicts updated MULTIPLE output and Figure C.2 exemplifies this. We make three new observations

1. The Pallet reserve area mostly covers the top half of Hall1
2. AUS pick is in Hall 3 in one way or another.
3. Receiving, packaging and loading are mostly in or around Hall 2

Most solutions resemble Figure B.1 in that AUS pick covers the lower and right parts of Hall 3 and thus does not have a logical shape. We follow the logic of placing AUS in Hall 3, but prefer a logical shape. Two options can achieve this: One is placing AUS pick in the left part of Hall 3 (Figure B.3). The other is placing it in the upper part (Figure B.4). We optimise for both solutions and choose the best.

#	1	2	3	4	5	6	7	8	9	10	11	12	Cost/ day
285	4	9	6	8	3	1	10	5	12	2	7	11	€ 458.16
823	4	8	6	9	3	1	10	5	12	2	7	11	€ 461.09
284	6	9	8	4	3	1	10	5	12	2	7	11	€ 461.24
582	4	9	6	8	3	1	10	5	12	7	2	11	€ 462.81
734	9	6	4	8	3	1	10	5	12	7	2	11	€ 462.85
223	2	9	8	3	1	12	10	5	6	4	7	11	€ 463.30
644	6	4	9	8	3	1	10	12	5	2	7	11	€ 463.64
392	6	9	4	8	3	1	10	12	5	2	7	11	€ 463.79
172	9	2	8	3	1	6	10	5	12	4	7	11	€ 464.46
636	4	9	6	8	3	1	12	10	5	2	7	11	€ 464.57

Table B.2 Top 10 Hessenpoort solutions with MULTIPLE

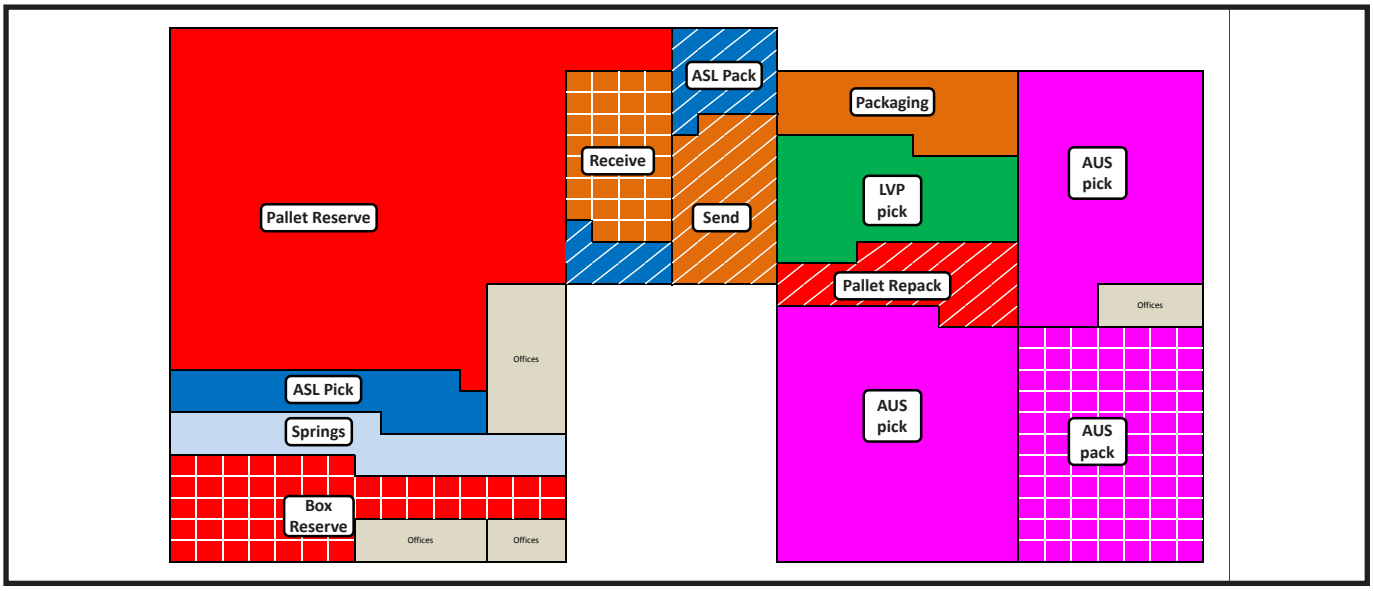

Figure B.2 Example of output

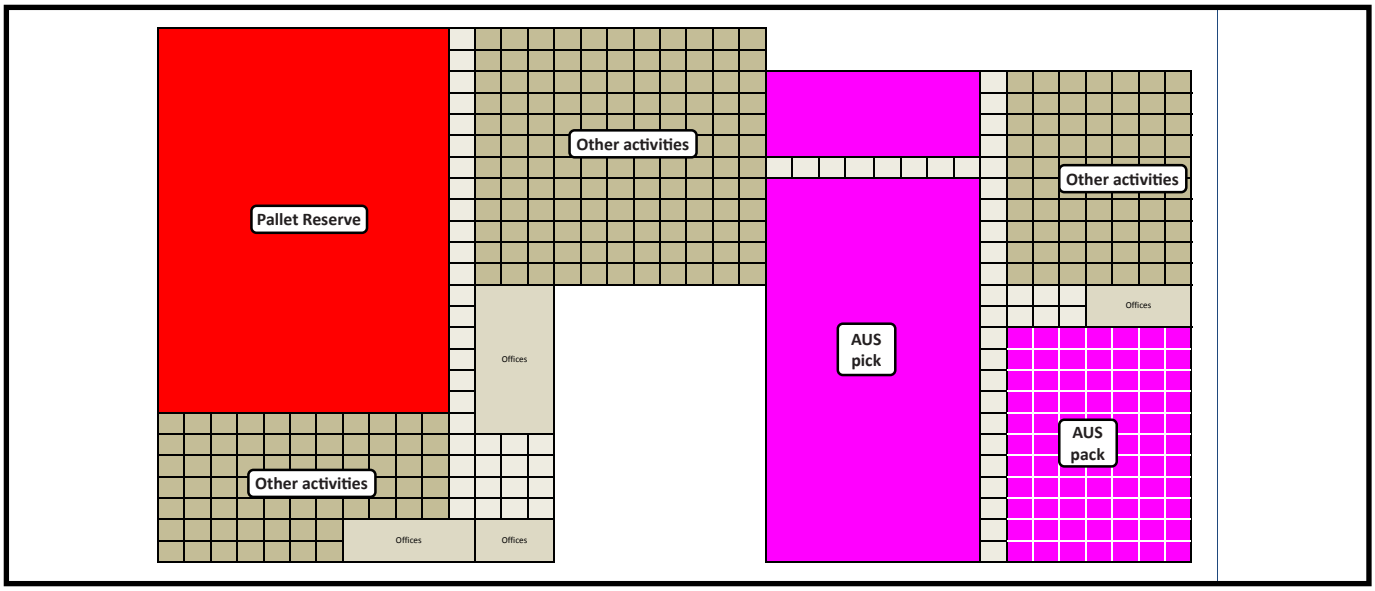

Figure B.3 Option I: AUS Pick in the left part of Hall 3

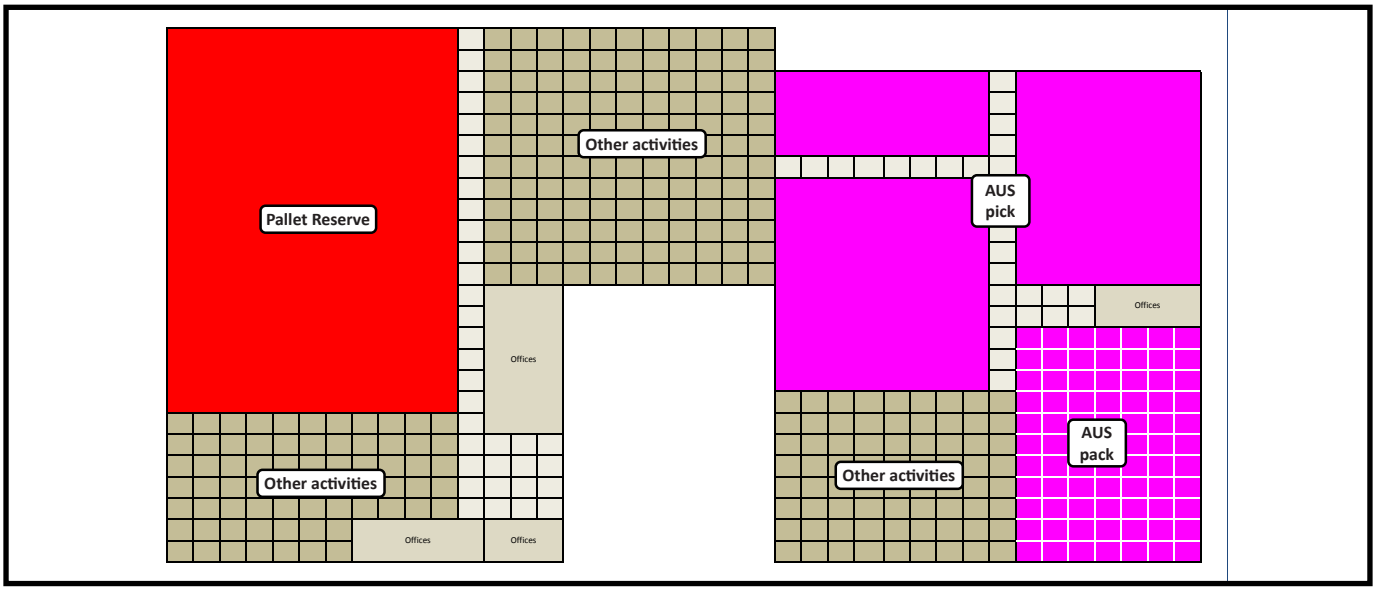

Figure B.4 Option II: AUS Pick in the upper part of Hall 3

B.1 CRAFT Hessenpoort- AUS in the left part of Hall 3

Based on the above findings, we construct an initial layout. We place the pallet repack area adjacent to the pallet reserve area. Place the ASL pick and pack adjacent to each other and further place the other departments. The solution in Figure C.4 has internal transport costs of 113.701. We perform CRAFT to this solution.

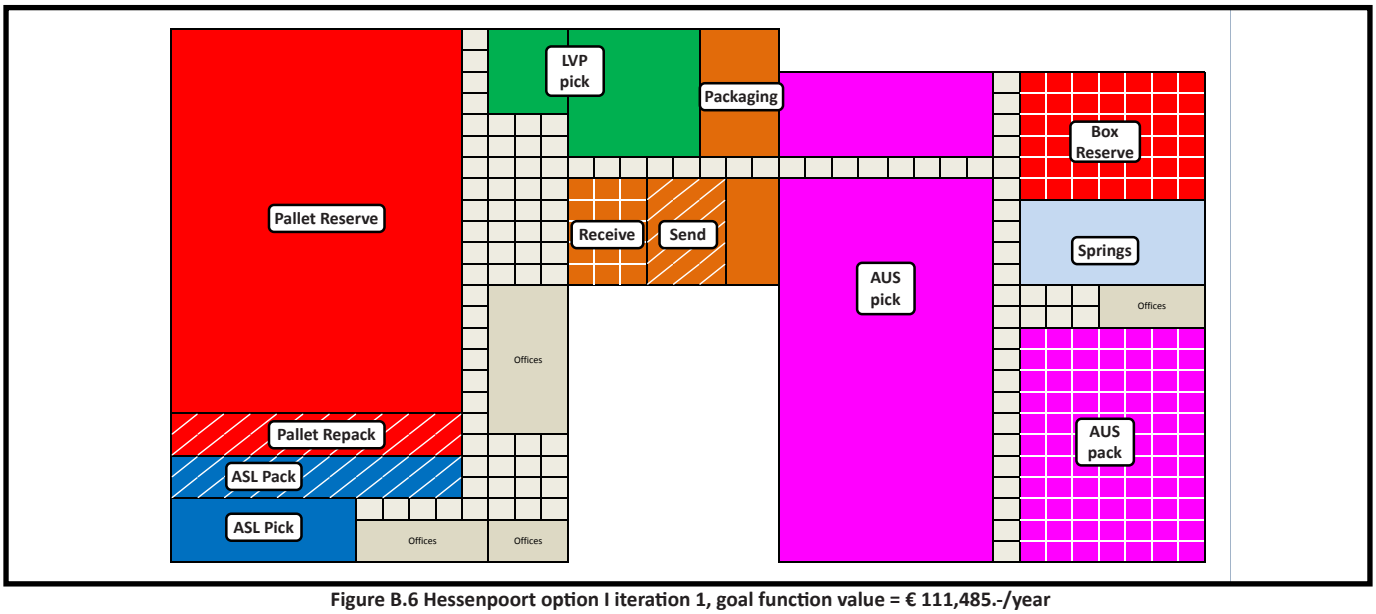

Figure B.6 Hessenpoort option I iteration 1, goal function value = € 111,485.-/year

We define the following exchange options:

Option	Relevant yearly costs
Current option	€ 111,485.-
Exchange pallet reserve area/pallet repack area	€ 110,454.-
Exchange receive/send	€ 112,259.-
Exchange send/ packaging	€ 110,613.-
Exchange Springs/Box reserve area	€ 110,916.-

Exchange LVP pick/ box reserve area	€ 112,224.-
Exchange receive/packaging/send	€ 116,463.-
Exchange ASL areas with box reserve area	€ 108,054.-

Table B.3 Exchange options iteration I

Exchanging the ASL areas with Box Reserve Area yields the largest goal function improvement. We apply this exchange (Figure B.6).

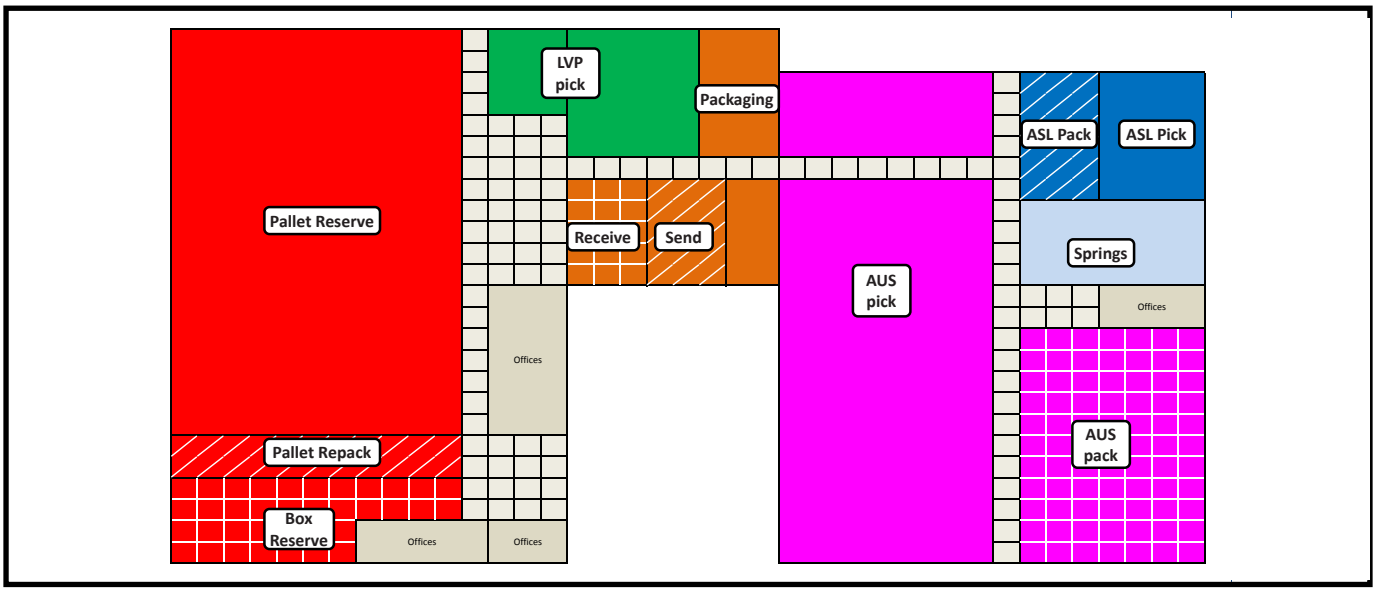

Figure B.6 Hessenpoort option I iteration 2, goal function value = € 108,054.-/year

We define the following exchange options and test their goal function values:

Option	Relevant yaerly year
Current option	€ 108,054.-
Exchange pallet reserve area/pallet repack area	€ 108,697.-
Exchange receive/send	€ 110,768.-
Exchange send/ packaging	€ 106,535.-
Exchange Springs/Box reserve area	€ 110,674.-
Exchange LVP pick/ box reserve area	€ 111,010.-
Exchange receive/packaging/send	€ 116,655.-

Table B.5 Exchanges option I iteration 2

Exchanging the Send/Loading area with the packaging area yields the largest goal function improvement. We apply this exchange (Figure B.7).

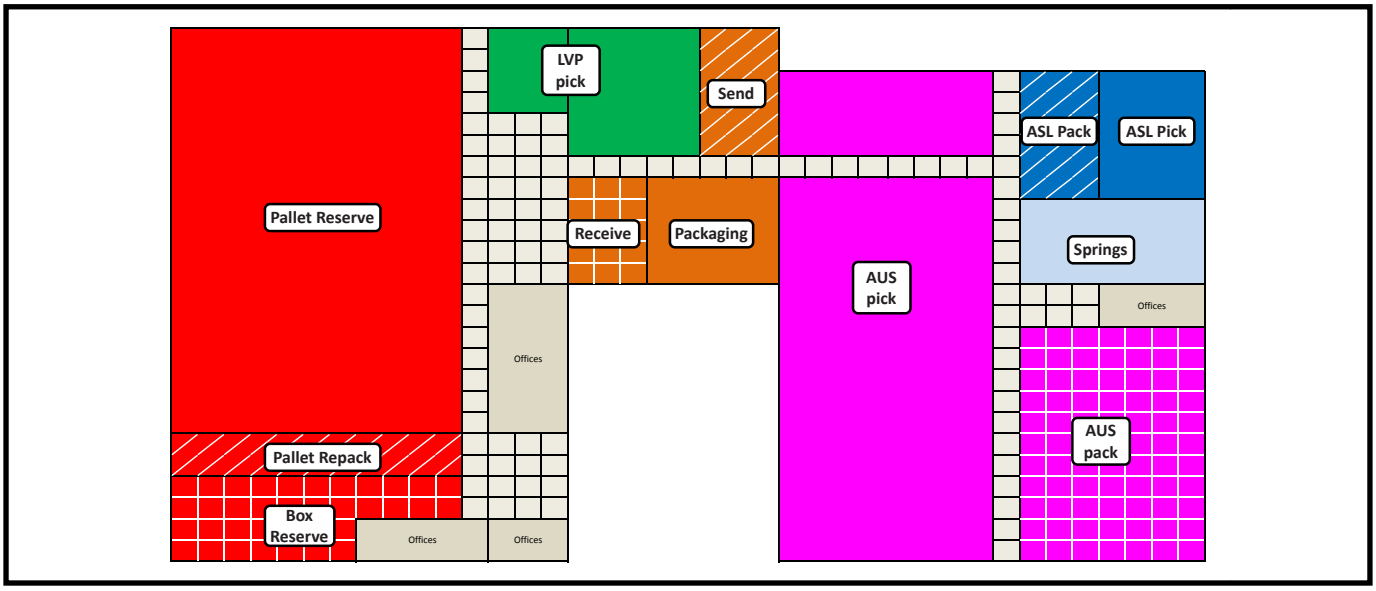

Figure B.7 Hessenpoort option II iteration3, goal function value = € 106,535.-

We define the following exchange options and test their goal function values:

Option	Relevant yearly costs
Current option	€ 106,535.-
Exchange pallet reserve area/pallet repack area	€ 107,174.-
Exchange receive/send	€ 116,609.-
Exchange send/ packaging	€ 115,414.-

Table B.5 Exchanges option I iteration 3

No improving solution was found, so we take this as solution for scenario I.

B.2 CRAFT Hessenpoort- AUS in the left part of Hall 3

For this scenario, we create a similar starting solution to the previous starting solution, where we place the Box Reserve Area and the springs with the AUS pick.

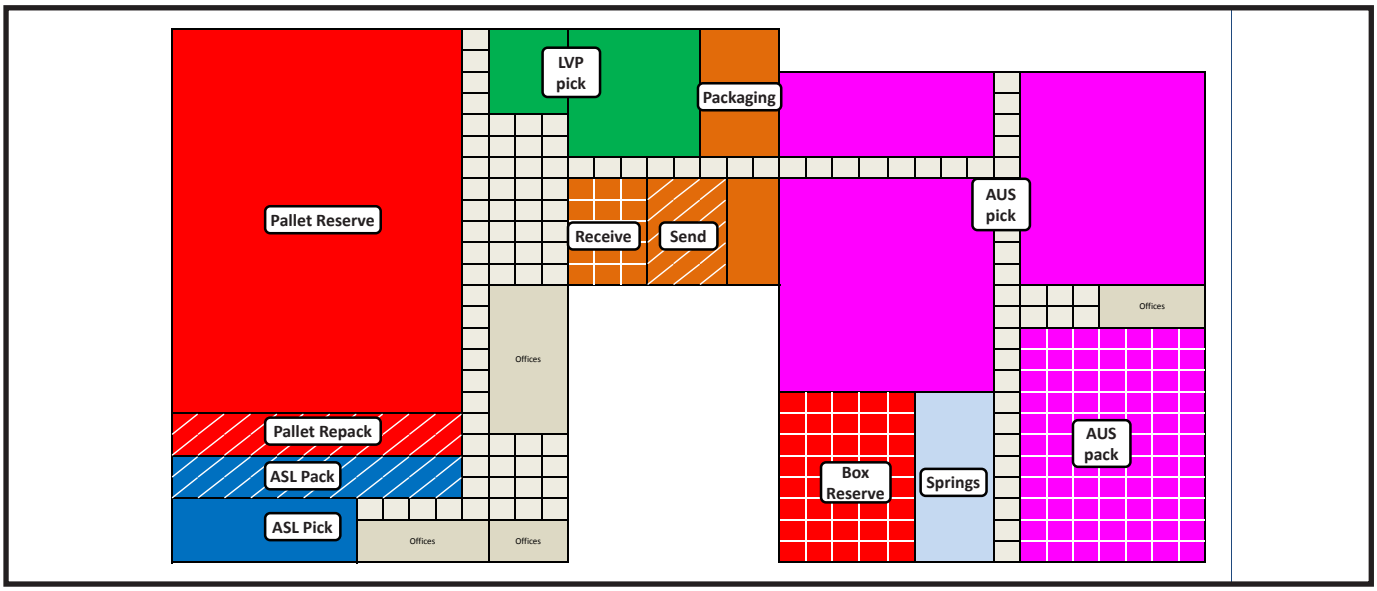

Figure B.8 Hessenpoort option II iteration 1, goal function value = € 119,703.-

We define the following exchange options and test their goal function values:

Option	Relevant yearly costs
Current option	**€ 119.703.-**
Exchange pallet reserve area/pallet repack area	**€ 119.890.-**
Exchange receive/send	€ 120.353.-
Exchange send/ packaging	**€ 118.880.-**
Exchange Springs/Box reserve area	€ 116.852.-
Exchange LVP pick/ box reserve area	€ 121.134.-
Exchange receive/packaging/send	€ 128.506.-
Exchange ASL areas with box reserve area	€ 119.491.-

Table B.6 Exchanges option II iteration 1

Exchanging Spring Picking with the Box Reserve Area yields the largest goal function improvement. We apply this exchange (Figure B.10).

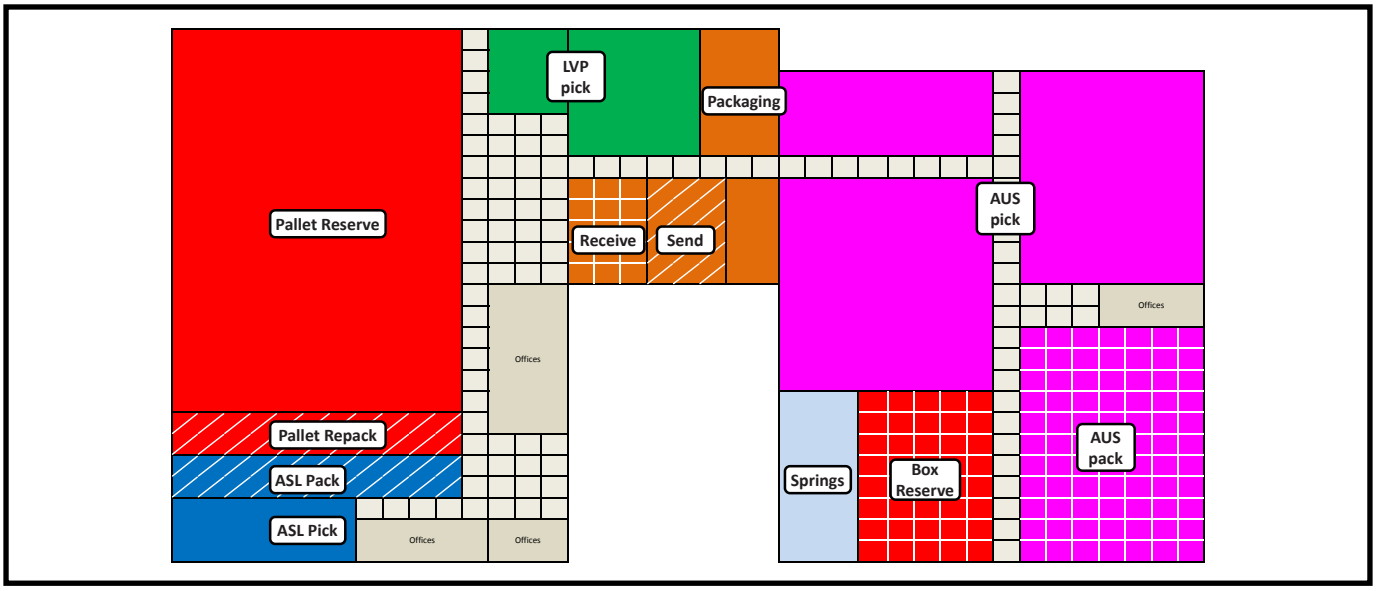

Figure B.10 Hessenpoort option II iteration 2, goal function value = € 113,099.-/year

We define the following exchange options and test their goal function values:

Option	Relevant yearly costs
Current option	**€ 113,922.-**
Exchange pallet reserve area/pallet repack area	**€ 114,232.-**
Exchange receive/send	€ 114,696.-
Exchange send/ packaging	**€ 113,099.-**
Exchange Springs/Box reserve area	€ 121,116.-

Table B.6 Exchanges option II iteration 2

Exchanging Spring Picking with the Box Reserve Area yields the largest goal function improvement. We apply this exchange (Figure B.10).

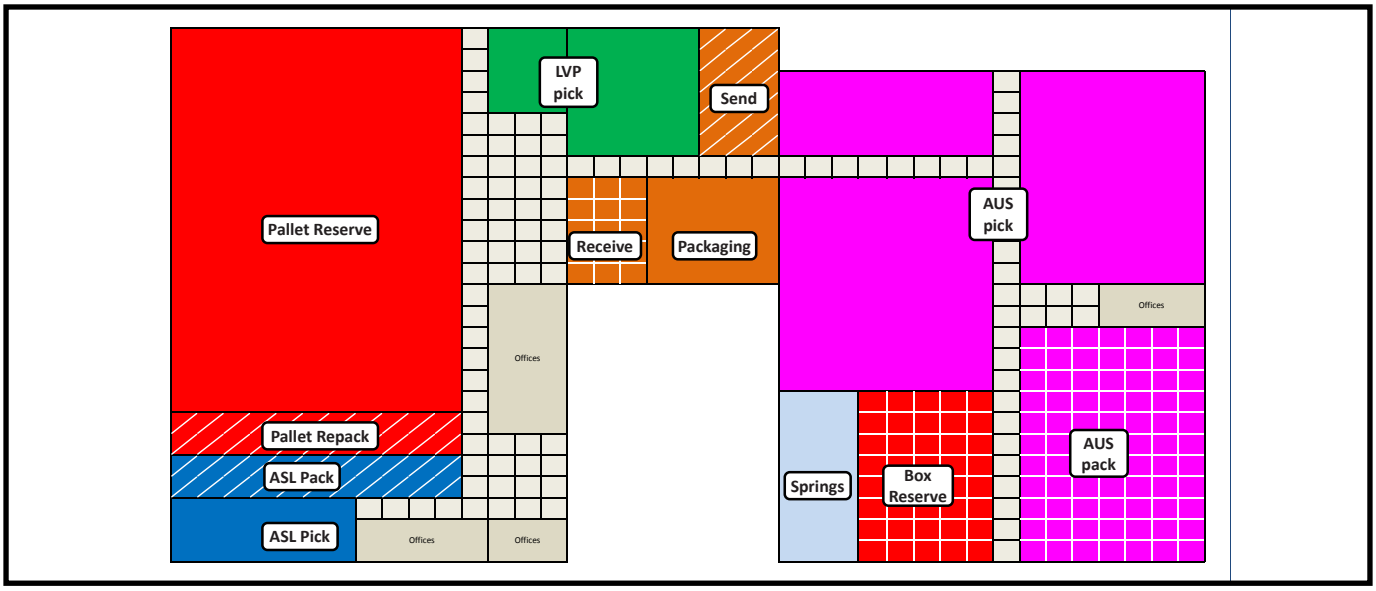

Figure B.11 Hessenpoort option II iteration 3, goal function value = € 113,099.-/year

We define the following exchange options and test their goal function values:

Option	Relevant yearly costs
Current option	€ 113,099.-
Exchange pallet reserve area/pallet repack area	€ 114,232.-
Exchange receive/send	€ 114,696.-
Exchange send/ packaging	€ 121,116.-

Table B.8 Exchanges option II iteration 3

No improving solution was found, so we take this as solution for scenario II.

B.3 Choice: AUS In the left part

The best of the 2 scenario's is to place AUS in the left part of Hessenpoort Hall 3, since it yields a lower goal function value. (€ 106,535.- vs. 113.009,-)

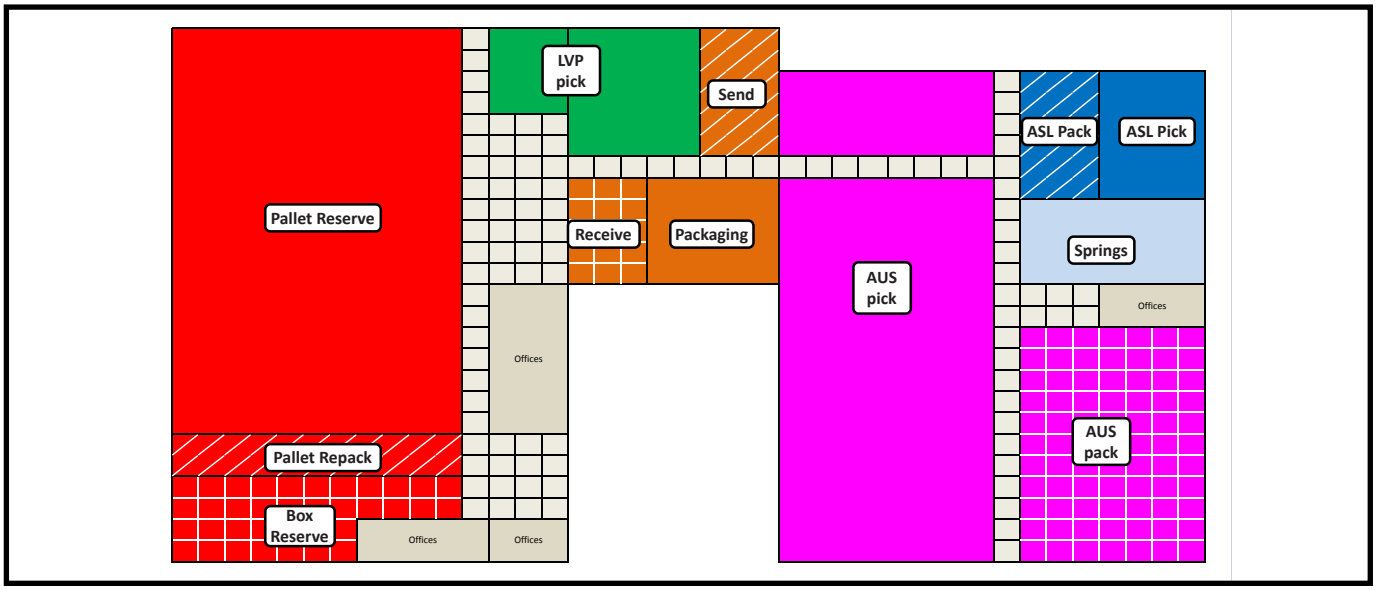

Figure B.12 Final Hessenpoort Solution.

C. Layout Staphorst- Excluding Zwolle Boxes

To determine important factors for good solution, we perform a MULTIPLE run. Table C.1 displays the sequence of departments and Figure C.1 exemplifies how this looks like.

In the best solutions, Main Flow and External are in a different hall, either Hall 1 or Hall 3. The packaging area is adjacent to either of the areas. This is logical, since the areas do not have any interactions with each other and the packaging area has interactions with both. Hence, we create a basic solution, on which we try to improve by applying department interchanges.

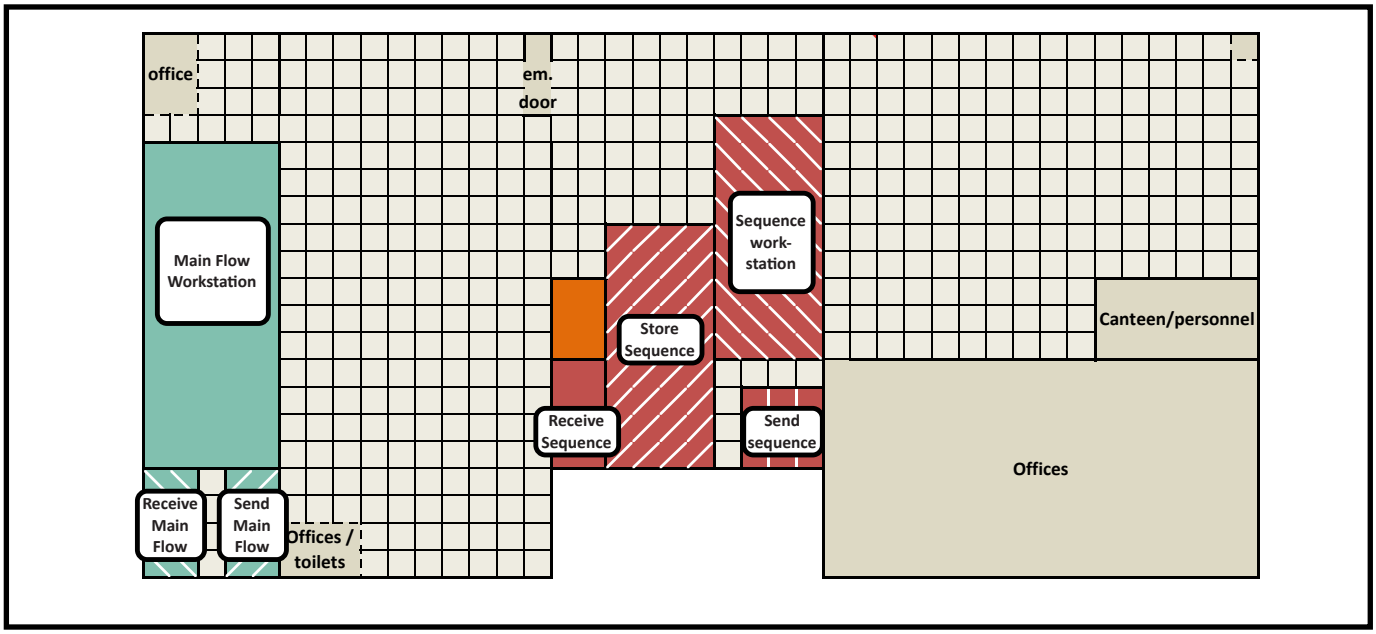

Figure C.1 Staphorst iteration 1, goal function value = € 47,718.-/year

For our exchange options, we do not try to exchange sequence/Main Flow functions, since no Main Flow function has any connection to any External Sequence function.

We define the following exchange options and test their goal function values:

Option	Relevant yearly costs
Current option	€ 47.718.-
Exchange pallet reserve area/pallet repack area	€ 51.255.-
Exchange receive/send	€ 57.654.-

Table C.1 Exchange options

In all top solutions, the box area is next to Hall 2 (In either Hall 1 or 3). The total amount of capacity is higher than required. We determined 1700 m² of capacity requirements for this function. This is about the size of Hall 2, therefore we place the boxes exactly at this Hall. To create a start solution for CRAFT, we combine this layout with the final Scenario I Staphorst layout (Figure E.2). We apply feasible exchange options to find a good solution (Figure D.2).

D. Layout Staphorst- Including Zwolle Boxes

This appendix gives a thorough overview of creation of the Staphorst layout for Scenario II. To determine important factors for good solution, we perform a MULTIPLE run. Table C.1 displays the sequence of departments and Figure D.1 exemplifies how this looks like.

#	1	2	3	4	5	6	7	8	9	10	11	12	Cost/ day
36	9	12	10	11	2	1	4	5	3	6	8	7	€ 594,18
42	9	12	10	11	3	4	7	5	8	1	2	6	€ 603,57
43	9	12	10	11	3	4	1	5	8	7	2	6	€ 605,44
31	12	9	11	10	3	4	1	8	5	7	2	6	€ 613,82
13	12	9	11	10	2	1	7	4	3	5	8	6	€ 614,42
6	12	9	11	10	2	1	7	8	4	3	6	5	€ 617,70
5	12	9	8	7	10	11	3	4	1	5	2	6	€ 617,88
19	8	9	12	10	11	3	7	4	5	1	2	6	€ 618,76
30	12	9	10	11	2	4	5	1	3	6	8	7	€ 624,52
4	12	9	8	7	10	11	3	4	5	1	2	6	€ 626,10

Table D.1 Top 10 Hessenpoort solutions with MULTIPLE

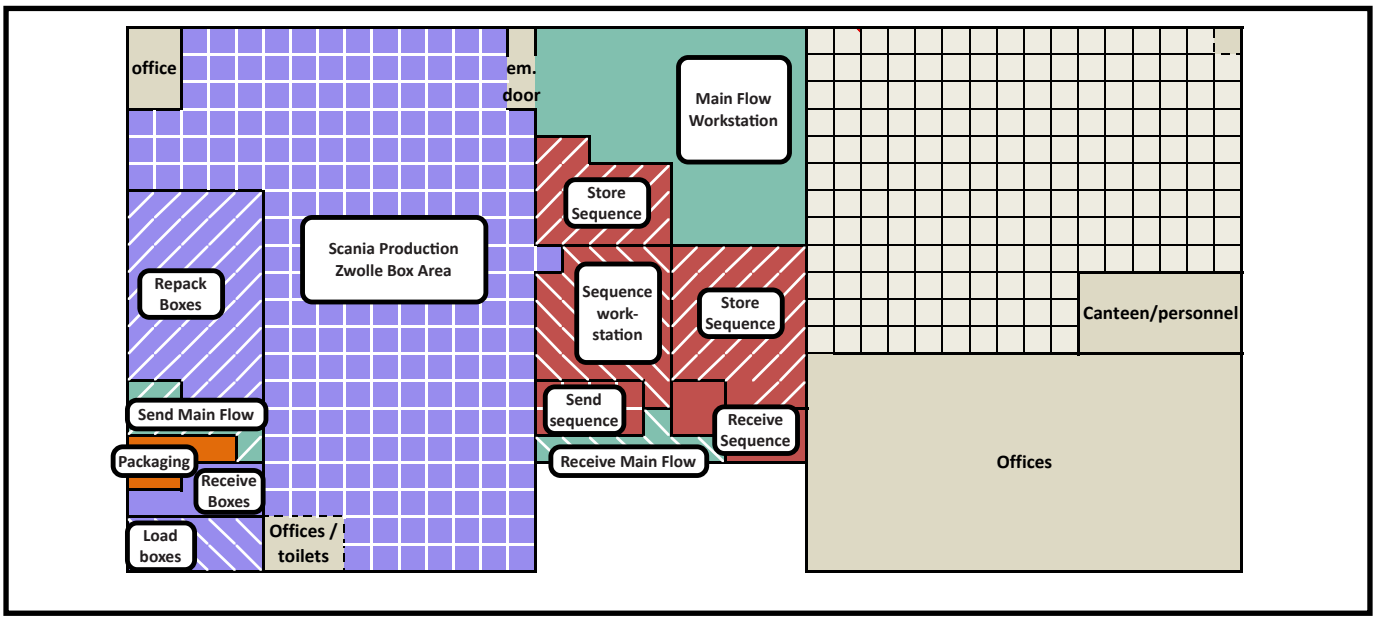

Figure D.1 Example of MULTIPLE output

In all top solutions, the box area is next to Hall 2 (In either Hall 1 or 3). The total amount of capacity is higher than required. We determined 1700 m² of capacity requirements for this function. This is about the size of Hall 2, therefore we place the boxes exactly at this Hall. To create a start solution for CRAFT, we combine this layout with the final Scenario I Staphorst layout (Figure E.2). We apply feasible exchange options to find a good solution (Figure D.2).

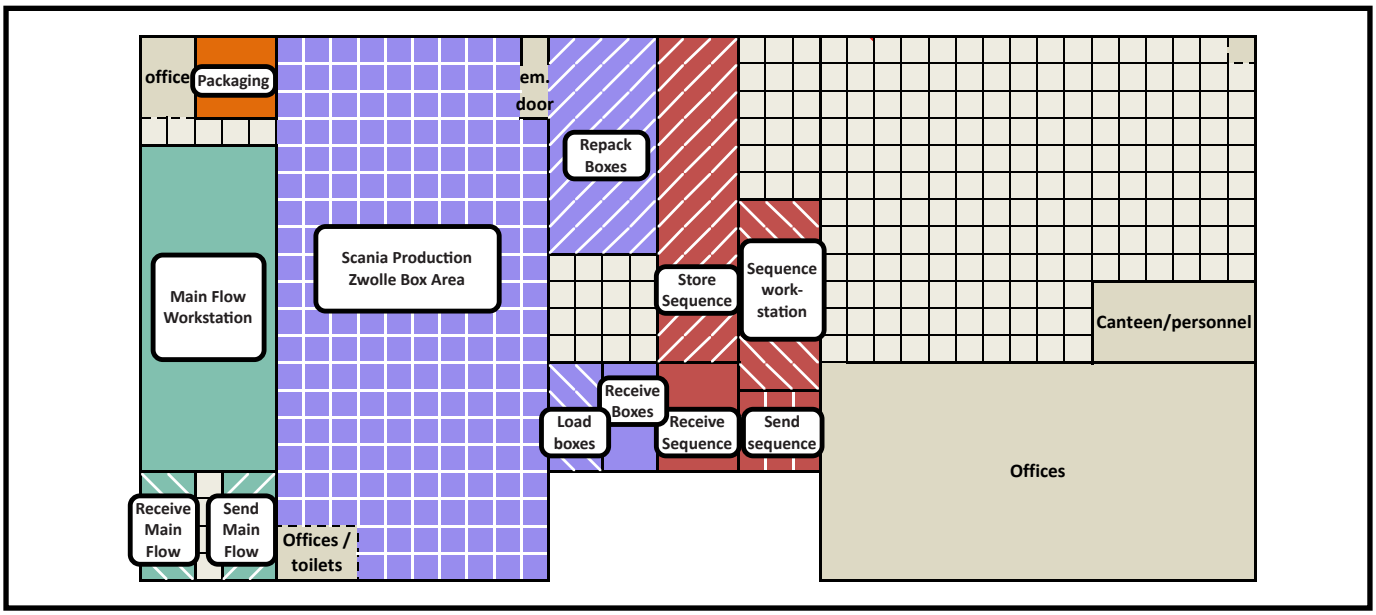

Figure D.2 Staphorst iteration 1, goal function value = € 111,126.-/year

We define the following exchange options and test their goal function values:

Option	Relevant yearly costs
Current option	€ 111,126.-
Exchange pallet reserve area/pallet repack area	€ 109,718.-
Exchange receive/send	€ 110,737.-
Exchange send/ packaging	€ 108,592.-

Table D.2 Exchange options iteration 1

Exchanging the External Sequence loading area with External Sequence receiving and the External Sequence workstation with the External Sequence Storage yields the best goal funciton improvement. We apply this option (Figure D.3).

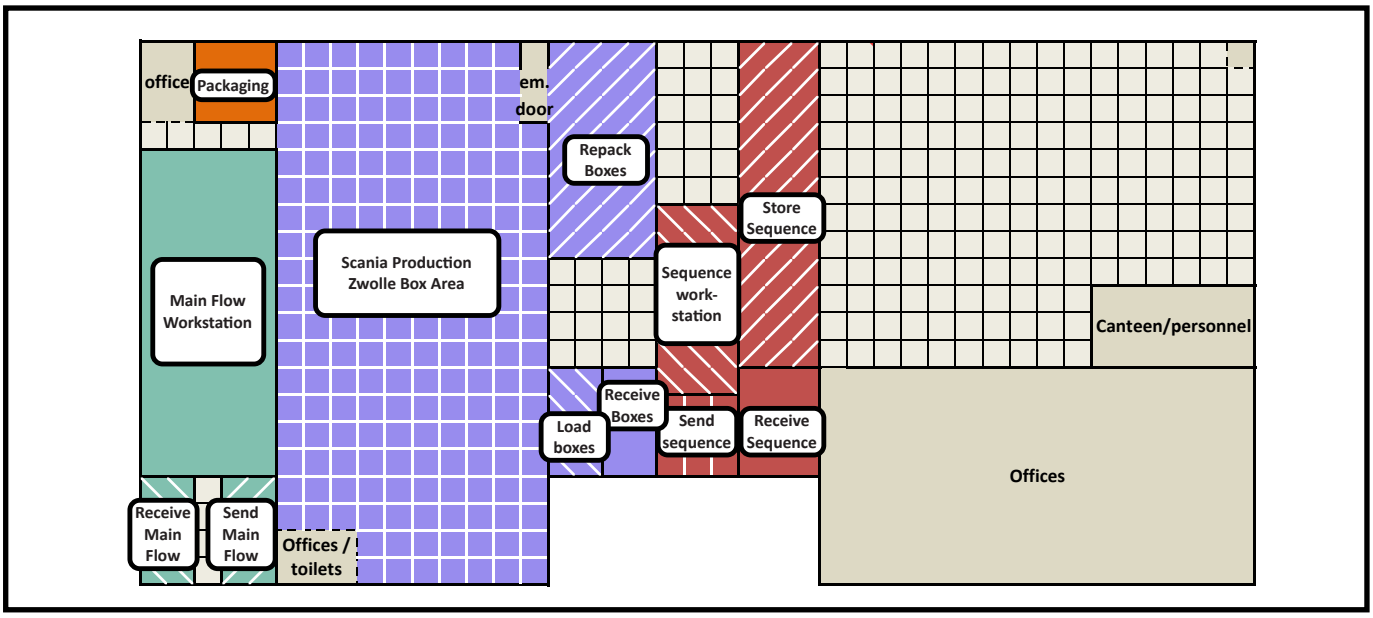

Figure D.3 Staphorst iteration 2, goal function value = € 108,592.-/year

We define the following exchange options and test their goal function values:

Option	€ 108,592.-
Current option	€ 107,184.-
Exchange pallet reserve area/pallet repack area	€ 108,533.-
Exchange receive/send	€ 114.696.-

Table D.3 Exchange options iteration 2

Exchanging load/receive (both Zwolle Boxes) yields the best goal funciton improvement. We apply this option (Figure D.4).

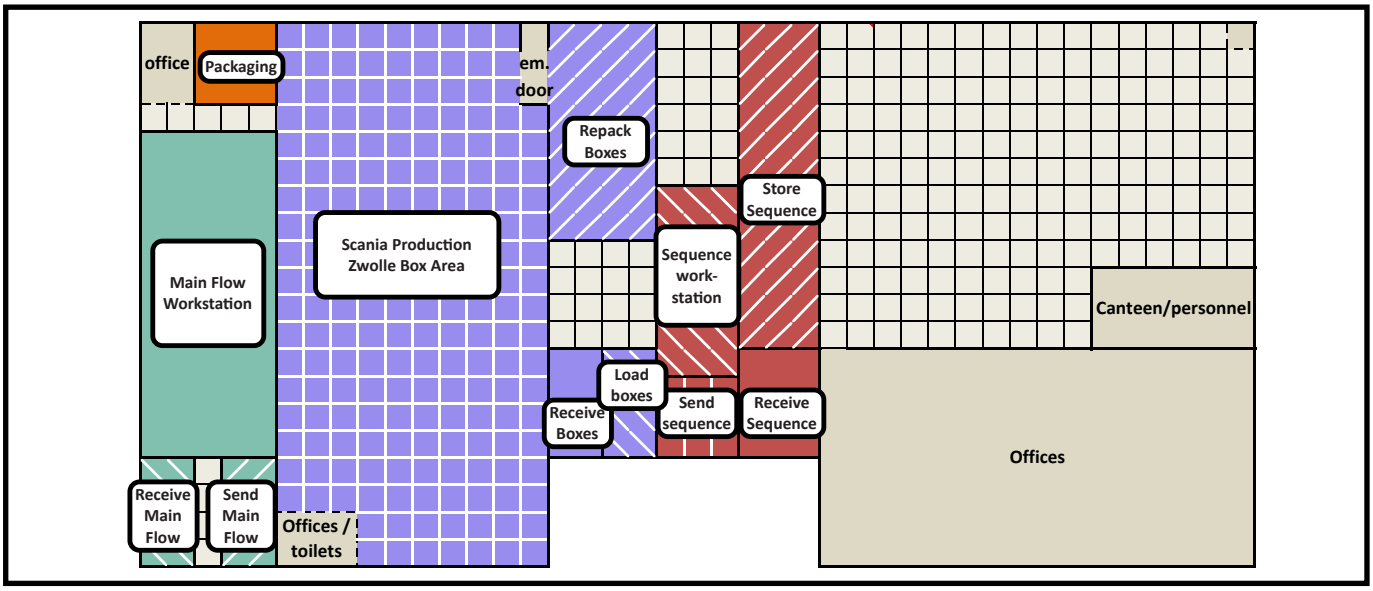

Figure D.4 Staphorst iteration 3, goal function value = € 107,184.-/year

We define the following exchange options and test their goal function values:

Option	Relevant yearly costs
Current option	€ 107,184.-
Packaging area to Hall 3 above External Sequence function	€ 107,125.-

Table D.4 Exchange options iteration 3

Moving the packaging area to Hall 3 yields the best goal function improvement. We apply this option (Figure D.5).

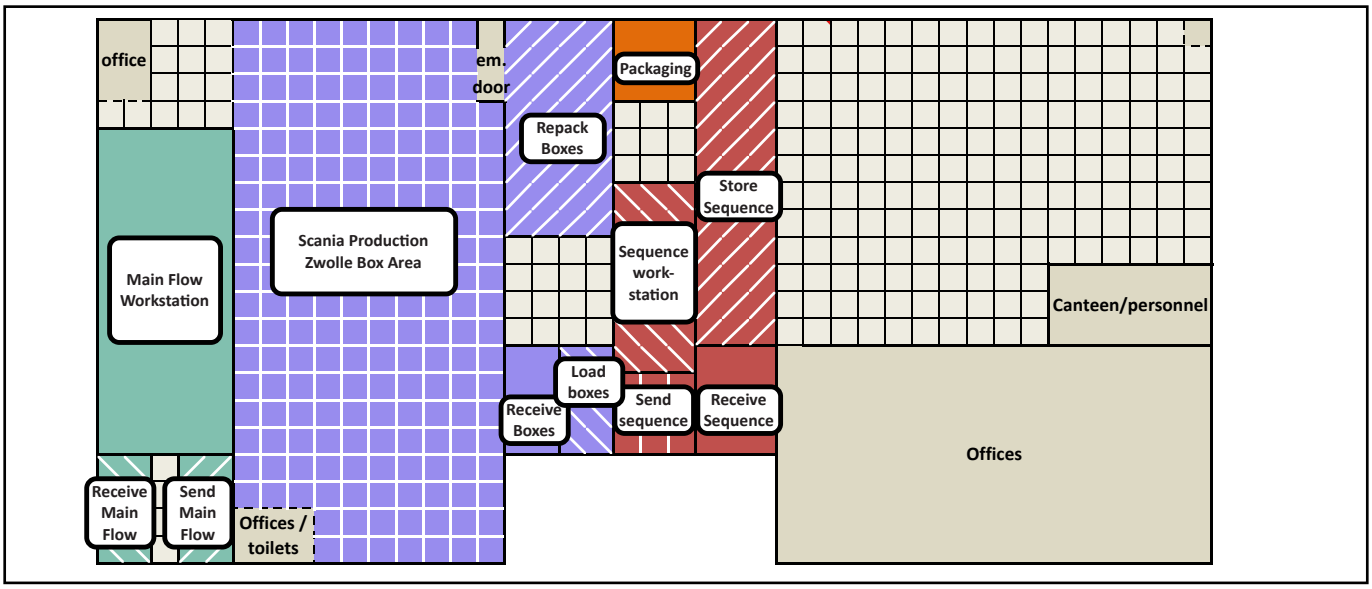

Figure D.5 Staphorst iteration 4, goal function value = € 107,125.-/year

We see not feasible exchange options anymore and thus set the final Staphorst layout for Scenario II to this layout.

E. Green Field Layout

Figure E.1 depicts the best MULTIPLE solution. Some elements seem logical: The receive area, send area and packaging area (the areas connected with outside) are near the building's edges. In addition, many connected areas are close to each other, e.g. AUS Picking and packing are adjacent.

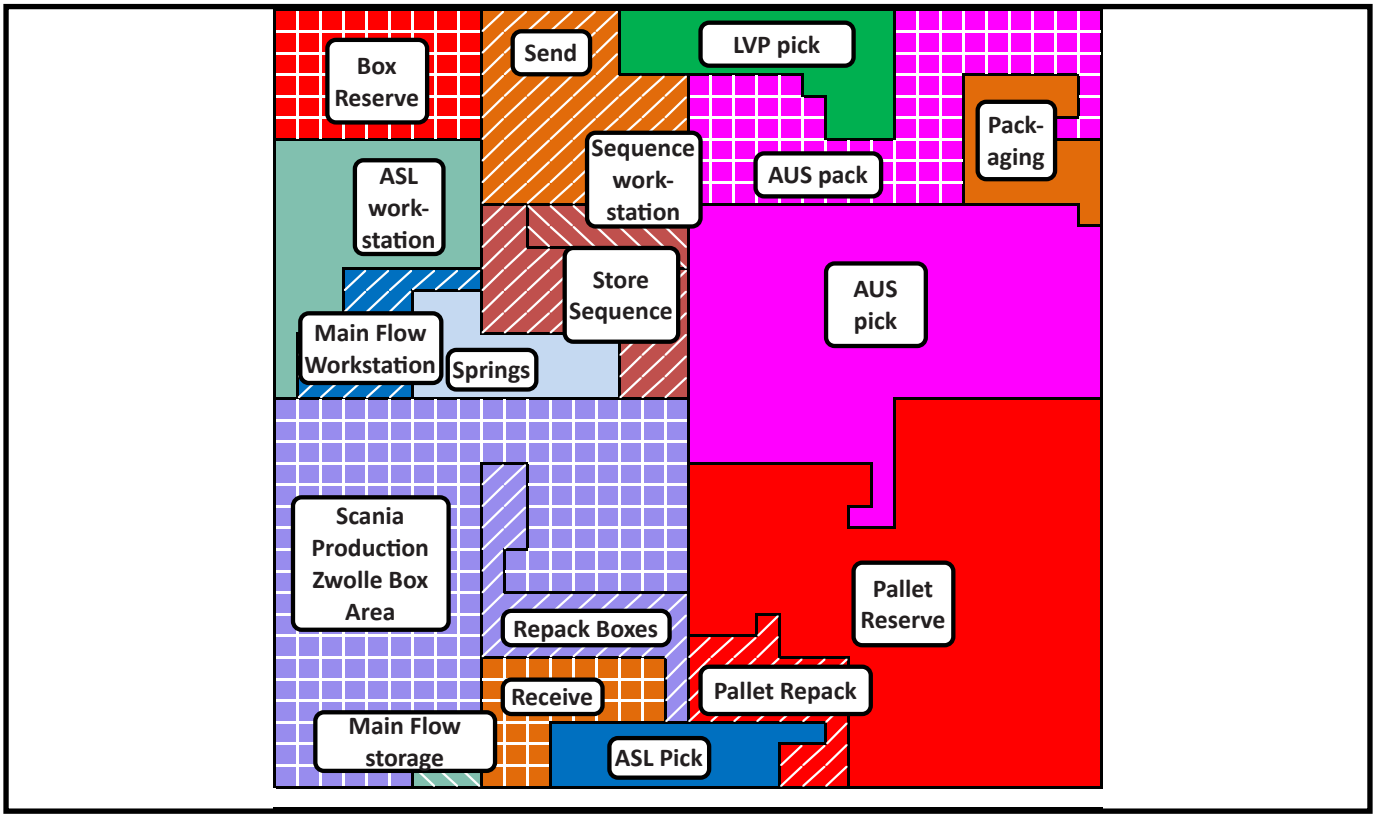

Figure E.1 MULTIPLE layout Green field situation with yearly costs € 268,218.-/year

We transfer the found MULTIPLE solution to a CRAFT input/starting solution:

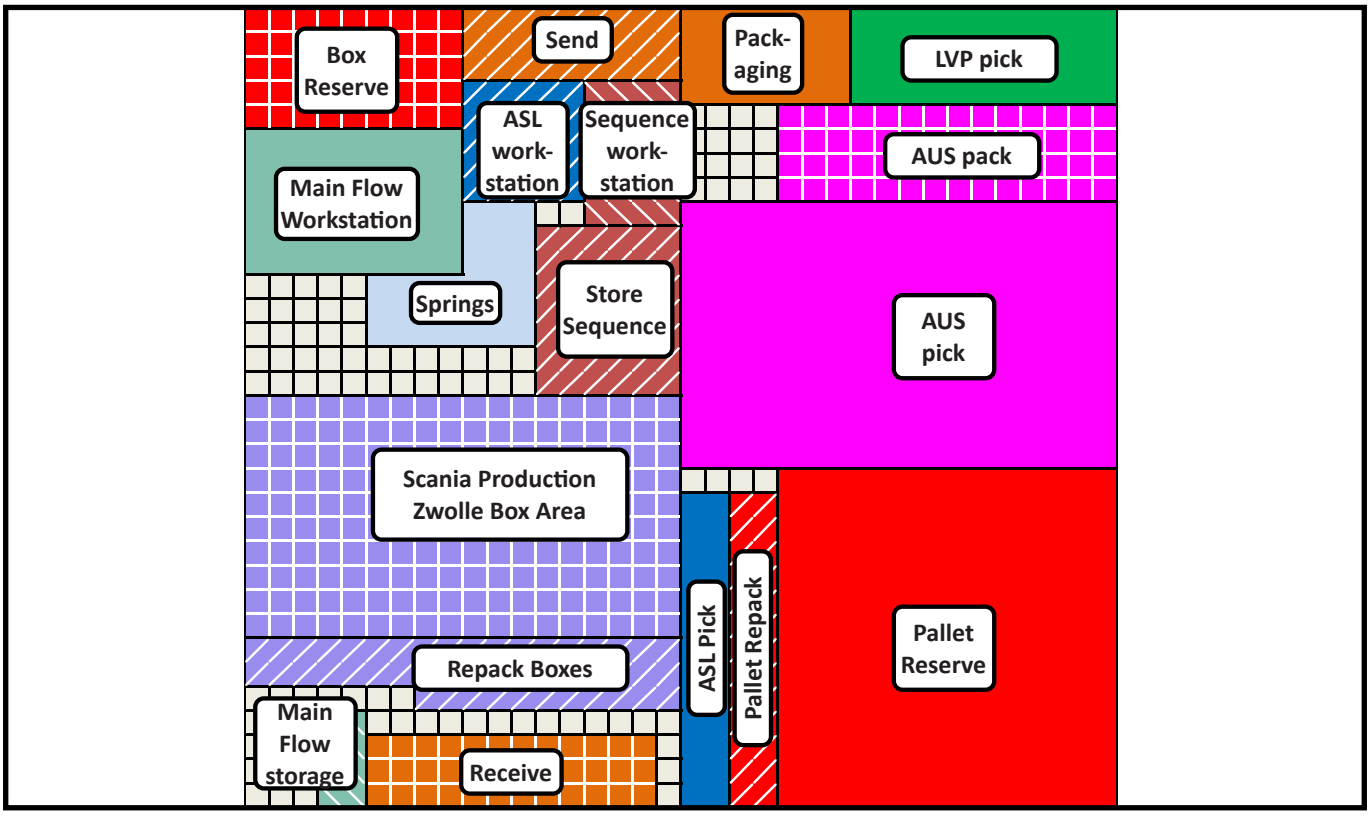

Figure E.2 Layout proposal 1 with total relevant costs = € 221,251.-/year

We define the following exchange options:

Option	Relevant yearly costs
Current option	€ 221,251.-
Exchange Pallet Repack/ASL Pick	€ 220,980.-
AUS pick/pack vertical instead of horizontal	€ 217,561.-
Main Flow store under Main Flow workstation	€ 221,251.-
Exchange Springs/Main Flow workstation	€ 221,336.-
Exchange Box Reserve/Main Flow workstation	€ 220,329.-
Exchange Box Reserve/Springs	€ 219,744.-
ASL Workstation next to AUS Pack	€ 223,032.-
Springs more to the right	€ 221,203.-
Exchange Pallet Reserve/Pallet Repack	€ 220,212.-
Exchange Reserve/Pallet Repack+ASL Pick	€ 220,138.-
Make Zwolle Boxes more narrow	€ 219,640.-

Table E.1 Exchange options proposal I

Placing 8/7 vertically next to each other instead of horizontally yields the best goal function improvement. We apply this option (Figure E.3)

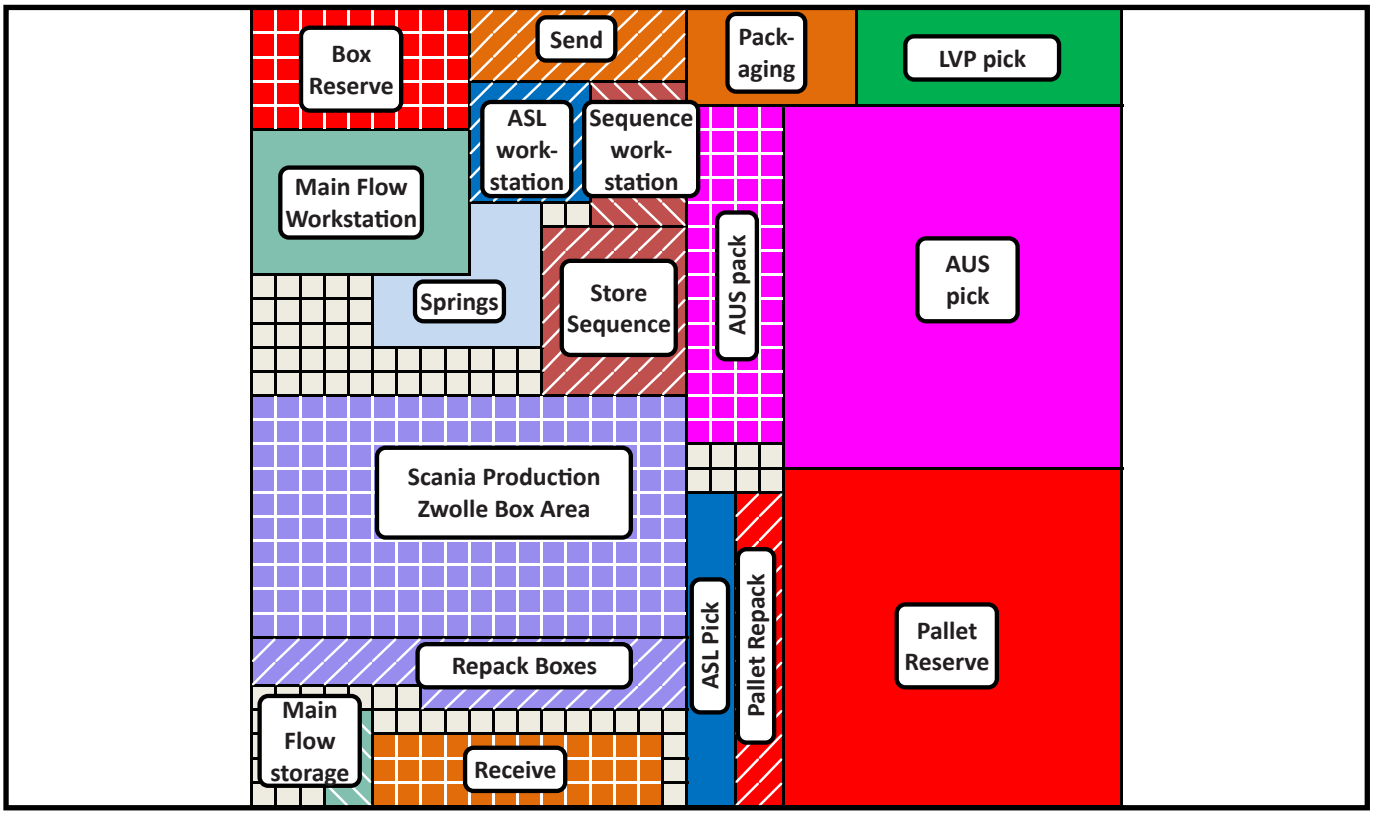

Figure E.3 Layout proposal II with total relevant costs = € 217,561.-/year

We define the following exchange options:

Option	Relevant yearly costs
Current option	€ 217,561.-
ASL Pick/Pallet Repack up	€ 217,790.-
Exchange Pallet Repack/ASL Pick	€ 217,291.-
Exchange Springs/ Main Flow workstation	€ 217,646.-
Move Main Flow workstation/Springs to the right	€ 217,298.-
Exchange Box Reserve/Main Flow workstation	€ 216,639.-
Exchange Box Reserve/Springs	€ 216,083.-

Table E.2 Exchange options proposal II

Exchanging departments 4/11 yields the best goal function improvement. We apply this option (Figure E.4)

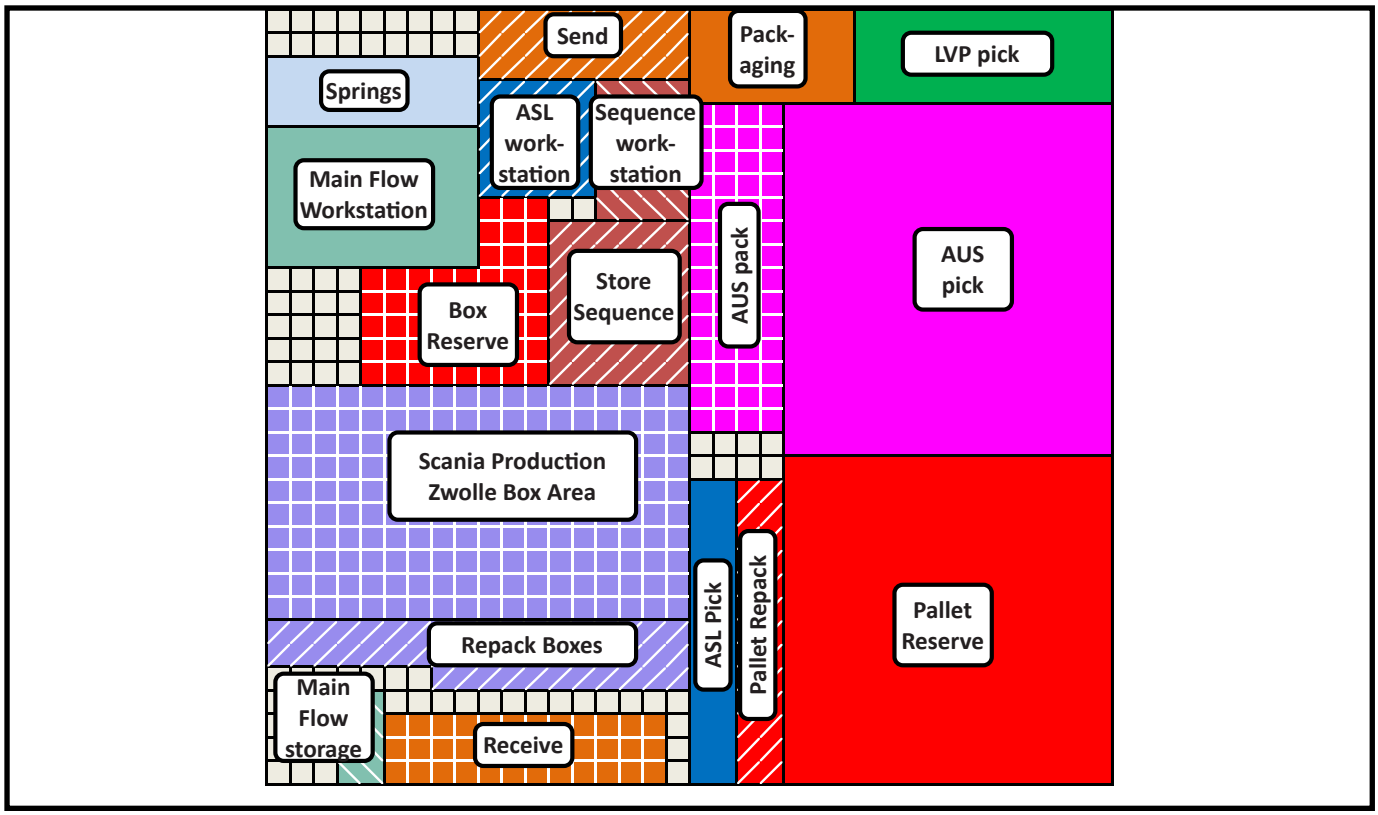

Figure E.4 Layout proposal III with total relevant costs = € 216,083.-/year

We define the following exchange options:

Option	Relevant yearly costs
Current option	€ 216,083.-
Exchange Springs/ Main Flow workstation	€ 216,140.-
Springs+Main Flow workstation down	€ 216,597.-
Exchange Pallet Reserve/ASL Pick+Pallet Repack	€ 214,901.-
Exchange Pallet Repack/ASL Pick	€ 215,812.-
Exchange Pallet Repack/Pallet Reserve	€ 215,380.-

Table E.2 Exchange options proposal II

Exchanging departments 3/2 yields the best goal function improvement. We apply this option (Figure E.5)

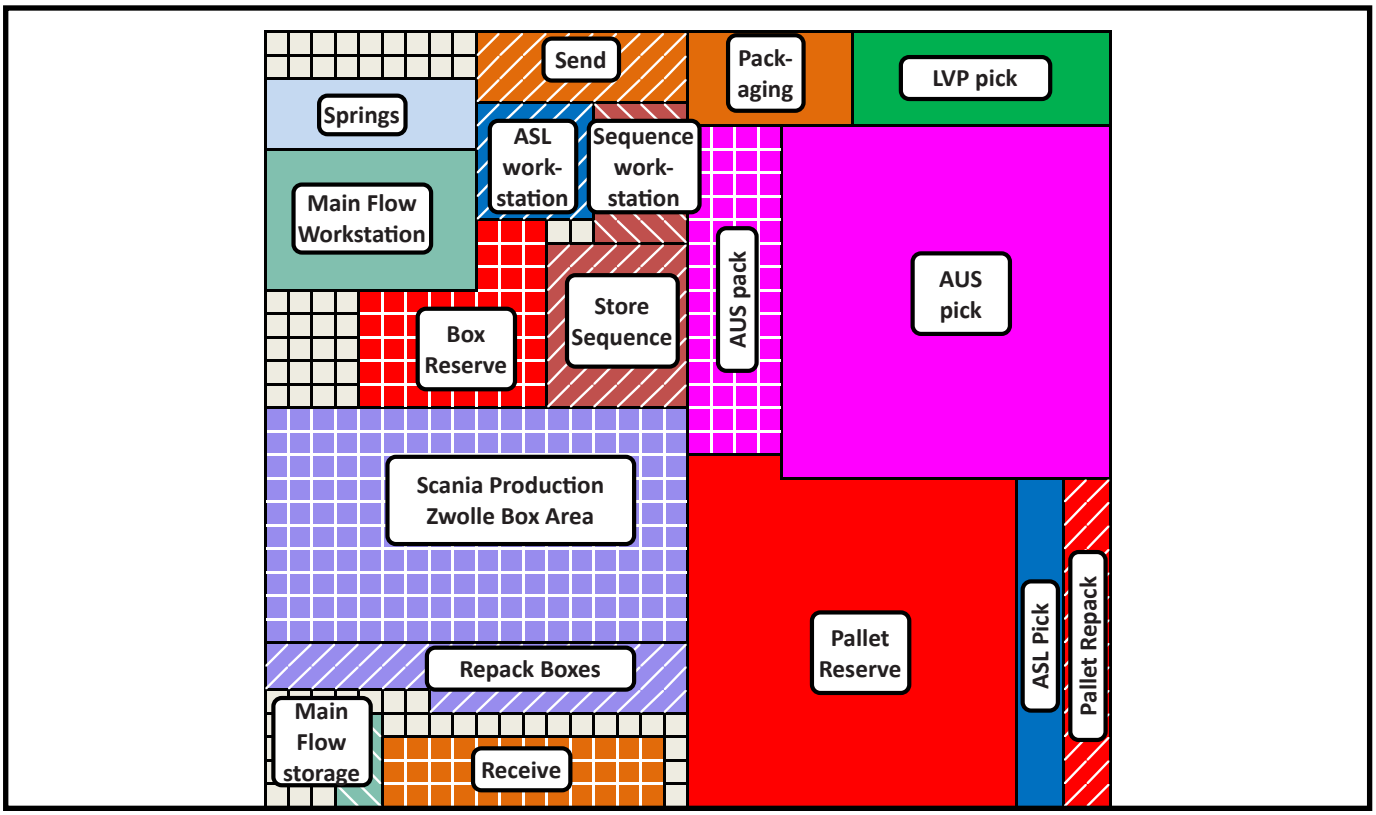

Figure E.5 Layout proposal V with total relevant costs € 215,380.-/year

We define the following exchange options:

Option	Relevant yearly costs
Current option	€ 215,380.-
Exchange Pallet Repack/ASL Pick	€ 215,650.-
Reduce Zwolle Boxes Repack/Zwolle Boxes, move Main Flow Storage & shift Springs + Main Flow workstation	€ 212,495.-

Table E.3 Exchange options proposal III

Exchanging departments 3/2 yields the best goal function improvement. We apply this option (Figure E.6) We see no feasible untested exchange options left, so we finalize the CRAFT output. We still apply one change to this final layout. The most left part of the facility has unused capacity. We cut this capacity away, while maintaining the solution quality.

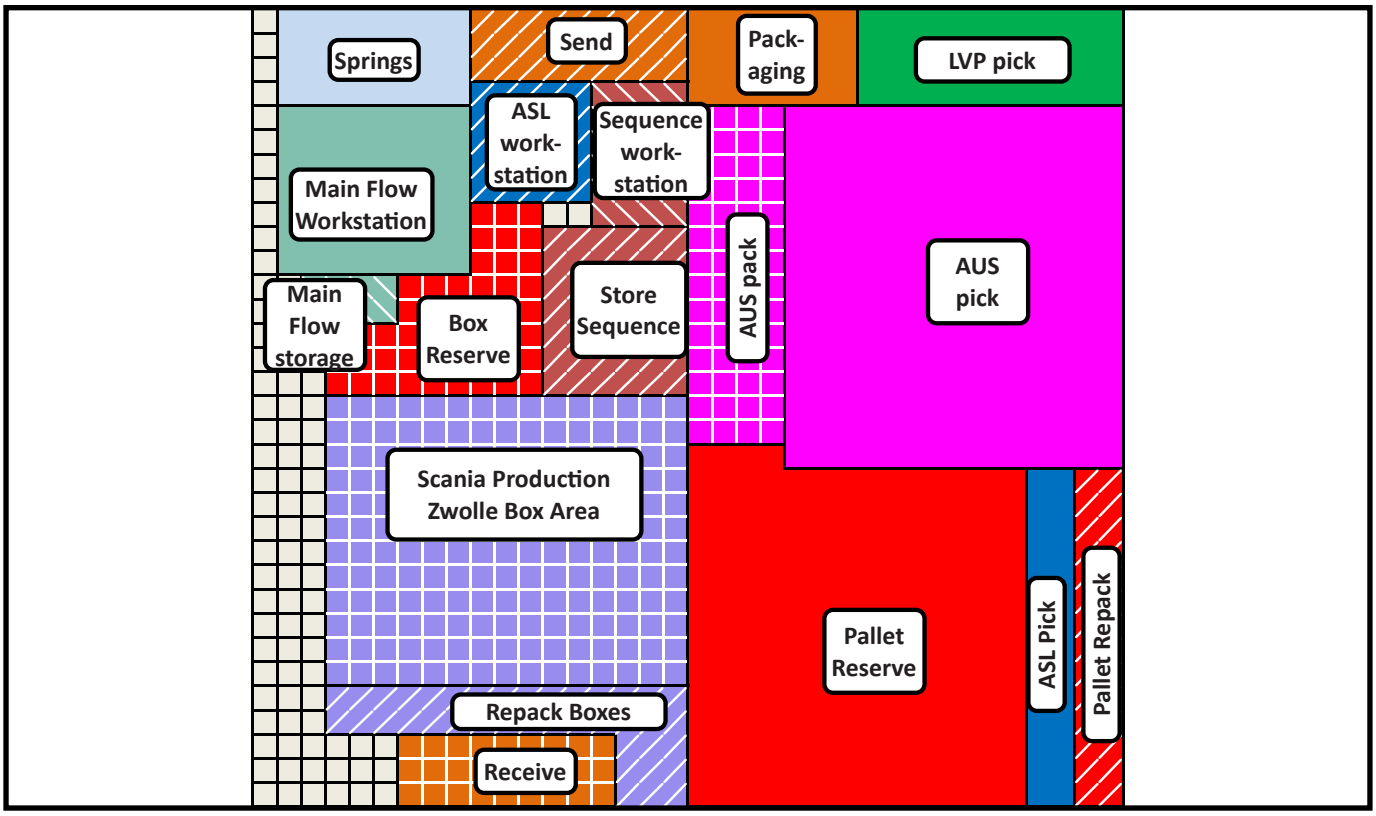

Figure E.6 Layout proposal V with total relevant costs € 212,495.-/year

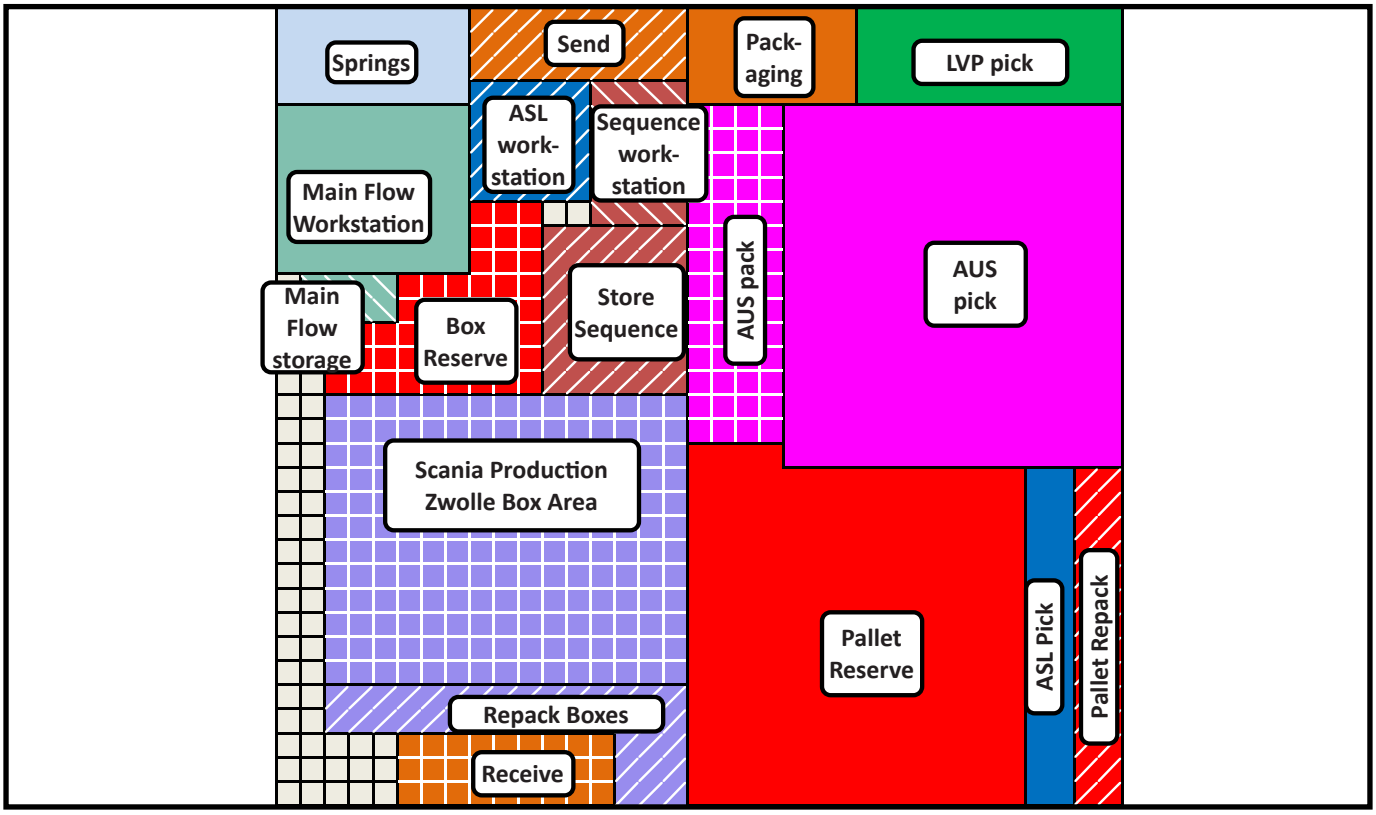

Table E.7 Layout proposal V, with unnecessary capacity cut away