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Improving the staging process in the warehouse of CEVA Logistics by introducing a dynamic staging policy to assign the shipments to the staging lanes

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Improving the staging process in the warehouse of CEVA Logistics by introducing a dynamic staging policy to assign the shipments to the staging lanes

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In partial fulfillment of the requirements for the degree of Master of Science in Operations Management and Logistics

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Abstract

This research is conducted at third-party logistics provider CEVA Logistics Eindhoven. Due to heavy competition in the third-party logistic market, third-party logistic providers have to reduce pick-to-ship cycle times to gain a competitive advantage. CEVA Logistics uses staging lanes to minimise the pick-to-ship cycle time within the warehouse. However, it regularly happens that packages do not arrive on time or get lost in the staging lanes due to congestion in the staging lanes. The main reason is that the staging lanes are dedicated to a single carrier and have a fixed capacity. To avoid congestion in the staging lanes, a dynamic allocation policy is proposed to assign shipments to a staging lane. To optimally assign these shipments to a staging lane, a staging lane assignment model is introduced. The staging lane assignment model minimises the total time a marshaller spends transporting packages from the pack locations to the staging lanes. To see whether the proposed allocation policy and the staging lane assignment model have the expected results, a situation with the proposed allocation policy and model will be compared to the current situation in a case study. The results show that applying a dynamic allocation policy together with the introduction of an issue lane, a minimal slack time of 60 minutes and an accurate forecast on the number of packages reduces the time spent on marshalling packages and the number of operational staging lanes.

Management summary

This report is the result of a master thesis project conducted at CEVA Logistics in Eindhoven. The focus of this report lies on the outbound process of CEVA Logistics Eindhoven's biggest customer in terms of volume: Sandvik.

Problem statement

In recent years, the competition has increased in the third-party logistics market (Barker et al., 2021). Due to this heavy competition, third-party logistic providers have to reduce costs to gain competitive advantages. One way to reduce costs is to reduce the pick-to-ship cycle time. The pick-to-ship cycle time within a warehouse with an external shipping carrier is the time between the release of an order and the order being loaded in the truck. CEVA Logistics tries to improve the pick-to-ship cycle time within the warehouse by using staging lanes. A staging lane is a short-term storage buffer to consolidate all the packages of a shipment. By using the staging lanes, the picking and packing process can start earlier, and the workload can be spread more evenly as they do not have to start just before the truck arrives.

However, at CEVA Logistics, it regularly happens that packages do not arrive on time at the staging lanes or get lost in the staging process. A reason for these delayed and lost packages is the congestion in the staging lanes. The congestion is mainly caused by the fact that CEVA Logistics uses a dedicated allocation policy for the staging lanes. A dedicated allocation policy means that every carrier has a fixed staging lane. All the staging lanes have a fixed size and no capacity constraint. These restraints make it possible for the warehouse management system (WMS) to assign packages to an already congested staging lane. Congestion in the staging lane results in a higher probability of packages not being located, resulting in manifests being dropped out of the shipment. Besides, dropped packages contribute to excessive shipment loading times, as the loading staff have to spend much time locating the packages, reducing the loading efficiency. Therefore, the following research question will be investigated:

How can the staging process be made more efficient by redesigning the staging lanes and optimising the staging lane scheduling at the warehouse of CEVA Logistics?

Research approach

The first part of the research question regards the redesigning of the staging lanes. For the redesign of the staging lanes, the main focus is on the staging lane allocation policy and the number and capacity of the staging lanes. The staging lane allocation policy is determined based on the current issues that CEVA Logistics faces and insights from scientific literature. The number and capacity of the staging lanes will be based on the allocation policy and on warehouse management system (WMS) data such as the number of arriving carriers, maximum volumes of shipments and available staging space.

After the staging lane allocation policy and the number and capacity of the staging lanes are determined, a model is proposed to solve the staging lane assignment problem. The goal of the model is to minimise the total distance a marshaller needs to travel to transport the packages of a shipment from the pack locations to the staging lanes by assigning the shipments to the staging lanes in such a way that no staging lane gets congested. In the model, set J represents the staging lanes to which the vehicle of set I can be assigned during the timeframes presented in set T. The release and departure times are assumed to be fixed in the model. Fixed release and departure times mean that when a vehicle is scheduled to arrive at 14:00, the vehicle will arrive at 14:00.

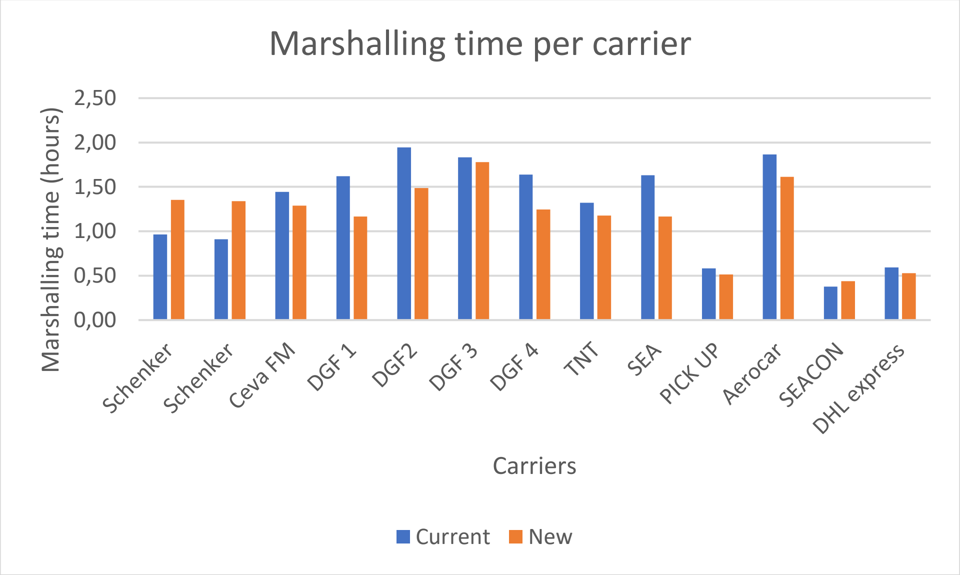
Delays, such as traffic jams or accidents, will not be considered. The release and departure times of the vehicles in set I are presented in set D and set R.

In a case study, the proposed model is applied to all daily arriving carriers of CEVA Logistics' customer Sandvik. The result of the case study will be compared to the current situation staging process to see whether the changes have the desired outcome.

Results

The number of staging lanes used to consolidate all the packages of a vehicle are less than in the current schedule. In the newly created staging lane schedule, the number of staging lanes used to temporarily store the packages before the shipment decreases from fifteen to nine. Especially, the number of staging lanes used for the four vehicles of a single carrier is reduced from seven to four. The decrease in staging lanes makes it easier for the expedition employees to locate the correct package for a vehicle, as all the packages are located in a single staging lane instead of searching for packages in different staging lanes.

The total time the marshallers are transporting the packages from the pack location to the staging lanes decreases from 16,73 hours to 15,11 hours per day. A decrease of 10,7%. Only three carriers have a longer marshalling time, as these carriers, in the current dedicated layout, had a staging lane relatively close to the pack locations. With the decrease in marshalling time, assuming that the productivity at the pack locations remains the same, the number of packages at the pack locations will most likely decrease, making it easier to collect packages at the pack locations.



The sensitivity analysis on the number of carriers shows that the dynamic staging policy outperforms the dedicated policy when the number of carriers goes up. Besides, the sensitivity analysis on the volume of the vehicles shows that the capacity of the staging lanes can be reduced without affecting the total distance travelled and the volume marshaller per hour. On the other side, lowering the capacity of the staging lanes increase the chance of an infeasible staging lanes schedule as there are too few staging lanes with enough capacity to handle the vehicles.

In addition, a sensitivity analysis was performed for the minimal slack time between two assigned vehicles. Lowering the minimal slack time decreases the total distance travelled by the marshaller and the number of operational staging lanes. However, reducing the minimal slack time to zero results in a staging lane schedule where vehicles are assigned to a staging lane directly after each other. With these tight assignments of vehicles, a small disruption could lead to changes in the staging lane schedule which is not beneficial for the total marshalling time. Therefore, CEVA Logistics should use a minimal slack time of 60 minutes.

Conclusion

Based on the results, the conclusion can be drawn that the staging process at CEVA Logistics can be made more efficient by switching from a dedicated allocation policy to a dynamic allocation policy in which the outgoing vehicles are assigned based on the minimal time a marshaller spends on transporting the packages from the pack locations to the staging lanes because this reduces the total time spent on the staging process. Besides, the dynamic staging lane allocation policy ensures that a staging lane can no longer become congested due to the capacity constraint and the introduction of the issue lane. Introducing the capacity constraint and the issue lane will result in a reduction of missing packages and a decrease in time spent on preparing a shipment to be loaded. Secondly, CEVA Logistics should keep a minimal slack time of 60 minutes between the assignment of two vehicles to the same staging lane to make the staging lane schedule robust for small delays. Finally, to properly assign the outgoing vehicles, it is important that the number of packages per carrier are correctly forecasted as the number of packages influences the assignment of the vehicle to the staging lane and, therefore, the pick-to-ship cycle time.

To successfully implement the suggested improvements, the following recommendations are formulated:

- Change the dedicated staging lanes physically and systematically into dynamic staging lanes.
- Implement the dynamic staging lane allocation policy in the WMS.
- Make it possible in the WMS to scan packages to the issue lane.
- Invest in the quality of the forecast of the shipments.
- Perform a periodic review of the shipped volumes to see whether the staging lane capacity is still sufficient.
- Perform a periodic review on the number of shipments to see whether the number of staging lanes is still sufficient.

Preface

This master thesis is the result of my graduation project for the Master in Operations Management and Logistics at the Eindhoven University of Technology. This thesis researches the assignment of outbound shipments to a limited number of staging lanes at the CEVA Logistics Eindhoven warehouse.

First of all, I want to thank dr. David Lai for his support during the writing of this thesis. Although almost all meetings were digital due to COVID, he was a great help with his feedback and support. David helped me approach the problem by providing me with other assignment related problems that were very useful to give me new insights. Moreover, I would also like to thank my second supervisor, dr. ir. Rob Broekmeulen for the supportive and helpful feedback on the project.

Next to my supervisors from the TU/e, I want to thank Dion Graafmans for the meetings and guidance over the last couple of months. Besides, I want to thank CEVA Logistics as a company and the engineering team for supporting me during the project.

I want to end by thanking my parents, sisters and girlfriend and friends for always supporting and motivating me during my study and this graduation project.

Thijn Nijsten

Eindhoven, April 2022

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List of Abbreviations

Abbreviations	
BAP	*Berth Assignment Problem*
CDAP	*Cross-dock Door Assignment Problem*
CPU time	*Central Processing Unit time*
DSBAP	*Discrete Static Berth Assignment Problem*
FTE	*Fulltime-equivalent*
GAP	*Gate Assignment Problem*
GHz	*Gigahertz*
HOPT	*High Order Picking Truck*
km	*Kilometer*
km/h	*Kilometer per Hour*
m/s	*Meter per Second*
MHE	*Material-handling Equipment*
MIP	*Mixed Integer Problem*
QC	*Quality Control*
RF	*Radio Frequency*
SKU	*Stock Keeping Unit*
WIP	*Work In Progress*
WMS	*Warehouse Management System*

Definitions

Term	***Definition***
Carrier	*An external company providing transport services*
Cross-docking	*"Cross-docking is a warehousing strategy that involves movement of material directly from the receiving dock to the shipping dock with a minimum dwell time in between" (Apte & Viswanathan, 2000, p. 291)*
Manifest	*A document specifying in detail the packages carried for a specific date and time, carrier and service level*
Package	*A Wooden or cardboard box that can contain one or multiple items*
Shipment	*Set of manifests going with one carrier*
Staging lane	*A short-term storage buffer to consolidate all the packages of a shipment*
Staging lane allocation policy	*Set of rules to assign a package to a staging lane*
Staging lane schedule	*A timetable that shows at which time frames a shipment is assigned to a certain staging lane*
Wave	*Orders for a common destination are released simultaneously for picking in multiple warehouse areas*
Zero picks	*An order picker finds no stock on item location*

1. Introduction

Due to a rising pressure for quick deliveries, more companies have decided to outsource their logistics processes to third-party logistic providers (Arif & Jawab, 2018). A third-party logistics party is described as “an independent service provider that performs a few or all of the logistics activities of the manufacturer of raw materials, work in progress (WIP), and finished products without taking ownership of these goods” (Pal Singh et al., 2022, p. 2). In recent years, the competition has increased in the third-party logistics market (Barker et al., 2021). The customers are becoming more demanding, and less loyal to suppliers (Frankin & Johannesson, 2013). Due to this heavy competition, third-party logistic providers have to offer customised services, such as consolidation and repacking, while trying to reduce costs to gain competitive advantages (Frankin & Johannesson, 2013). One way to reduce costs is to reduce the pick-to-ship cycle time (Boonsthonsatit & Jungthawan, 2015; Blomqvist, 2010). The pick-to-ship cycle time within a warehouse with an external shipping carrier is the time between the release of an order and the order is loaded in the truck (Gallien & Webe, 2010).

A company present in the third-party logistic market is CEVA Logistics. CEVA Logistics is a third-party logistics company that aims to unlock value in every step of the supply chain. They try to do this by fulfilling the customers' supply chain needs with custom logistic designs that fit these needs (CEVA Logistics, 2021). Located in Eindhoven, CEVA Logistics provides logistic services to Sandvik. Sandvik is a global engineering group that works in the mining, engineering, automotive, energy, and construction industry. Sandvik tries to drive innovation and digitalisation to unlock large-scale value, improve operations, create safer operating conditions, and achieve more with less with their customer (*Business Model — Sandvik Group*, n.d.).

CEVA Logistics tries to improve the pick-to-ship cycle time within the warehouse by using staging lanes. A staging lane is a short-term storage buffer to consolidate all the packages of a shipment. By using the staging lanes, the picking and packing process can start earlier, and the workload can be spread more evenly as they do not have to start just before the truck arrives (Meints, 2015). Another advantage of using staging lanes is that employees who load the trucks have a better overview of what packages are ready for loading. A better overview of the available freight can lead to a tighter pack of freight while loading as the employees know what to load. Ultimately, the tighter pack of freight reduces transportation costs because more freight can be stored in the truck (Luo & Noble, 2012).

However, at CEVA Logistics, it regularly happens that packages do not arrive on time at the staging lanes or get lost in the staging lanes, as presented in figure 1. One reason for these delayed and lost packages is the congestion of packages in the staging lanes, as presented in Appendix A. Congestion of packages in the staging lanes increases the probability of packages not being located, resulting in packages being dropped out of the shipment (Van Niekerk, 2017). Dropped packages contribute to excessive shipment loading times, as loading staff has to spend much time locating the packages, reducing the loading efficiency (Van Niekerk, 2017).

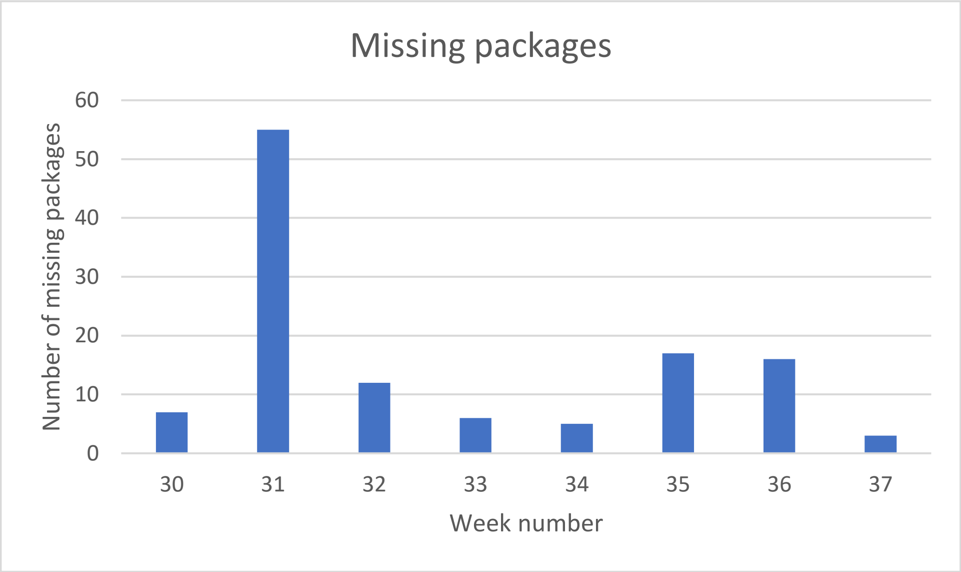

Figure 1: Number of missing packages

Another reason for the delayed and lost packages is that CEVA Logistics uses a dedicated allocation policy for the staging lanes. A dedicated allocation policy means that every carrier has a fixed staging lane (de Koster et al., 2007). All these staging lanes have a fixed size and systematically no limit on the number of packages that can be stored. These missing constraints make it possible for the warehouse management system (WMS) to assign packages to an already congested staging lane. For example, when a shipment is delayed, the next wave of orders for that carrier can already be released. Resulting in packages arriving at the staging lane before the delayed shipment has left. The packages of the next wave will most likely exceed the capacity of the staging lane, resulting in a congested staging lane. Alternatively, packages will not be marshalled to the staging lane because it is already congested, which will result in a congested packing location.

In third-party logistics literature, there is little research about the scheduling and design of the staging process. Instead, research mainly focuses on cross-dock locations (Apte & Viswanathan, 2000; Gue & Kang, 2001; Luo, 2018). At cross-dock locations, packages are delivered by different carriers and then consolidated based on delivery location. However, at CEVA Logistics, only a very small part of the shipped packages is cross-docked. Therefore, the following research question will be investigated:

How can the staging process be made more efficient by redesigning the staging lanes and optimising the staging lane scheduling at the warehouse of CEVA Logistics?

The scientific relevance of this study is that it contributes to the research gap by providing new insights into current scheduling staging lanes. At the same time, the managerial relevance is that this study aims to contribute to a more efficient approach to staging, which will be beneficial in terms of process time (Imai et al., 1997b). With regard to the societal relevance, this research aims to decrease the number of missing packages occurring during staging. As a result of the decrease in missing packages, a carrier only has to travel once to a customer to deliver the package(s) instead of going multiple times due to the missing packages, resulting in a reduction of emissions, as there is no need for an additional trip which contributes to a more sustainable approach within the logistical market (Ülkü, 2012).

1.1 The current outbound process of CEVA Logistics

In this section, the current outbound process of CEVA Logistics will be presented to get an overview of which processes affect the shipping of the packages and who is responsible for which processes.

The CEVA Logistics warehouse is operational from 05:30 until 0:00 during the weekdays and on Saturday from 5:30 until 18:00. The day is divided into two shifts, a day and an evening shift. During working hours, the outbound operation prepares outgoing shipments to be shipped out. Normally, these outbound shipments consist of multiple manifests. A manifest is a document specifying the item(s) carried for a shipment on a specific date and time, carrier, and service level. Most of the time, a manifest contains multiple different items that need to be picked, packed, and marshalled before they can be loaded into the truck, as presented in figure 2.

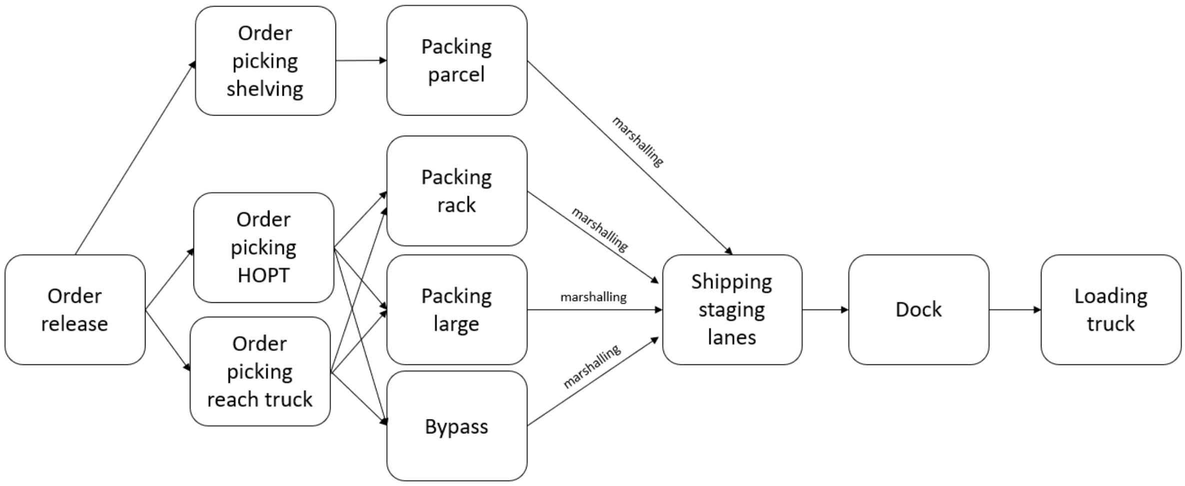

Figure 2: Process overview of CEVA Logistics outbound

The outbound process starts with the release of a wave in the WMS by the process controller. The process controller is responsible for completing the pick and pack process on time. A wave contains all the items of an outgoing shipment for a particular carrier. All the waves are released based on a wave plan which indicates when to release a wave. The wave plan is based on the pick-up time of the shipments and the historical data about the processing time of the shipment to determine the time a wave has to be released. When the process controller releases an order based on the wave plan, the wave cannot exceed a predetermined limit of items or capacity as a wave cannot exceed the truck's capacity.

In addition, the ratio of the number of racking and shelving items is taken into account to ensure that the order pickers in both areas have sufficient work during the day. However, the process controller is allowed to deviate from the wave plan when, for example, the reach truck drivers do not have any pick assignments left. The process controller can decide to release a wave earlier to ensure that the reach truck pickers do not run out of pick assignments. After the wave has been released, the WMS assigns the picking assignments to the orders pickers based on the priority of the picking assignment. The process controller has to manually add the priority of the pick assignments of a wave.

After the orders have been released, the items of a shipment will be picked. The picking area can be divided into two picking locations, the racking area and the shelving area. The racking area contains larger items that are not pickable by hand because of their size or weight. The items are being picked by HOPT (High Order Picking Truck) and reach trucks. The shelving area contains smaller items that can be picked by hand. The pickers in the shelving area use a trolley to collect multiple items within one route.

In both picking areas, the order pickers use hand scanners. These hand scanners indicate to which location the order picker has to go. When the picker has arrived at the indicated location, the picker needs to scan the barcode of the indicated location. When the picker scans the right location, the scanner shows the item's name and the quantity. The pick routing is based on source location, the item's final destination and shipment ID.

To determine the average productivity per picking area, data of 29 days were taken in October and November 2021. Outliers were removed from the data using a boxplot because they give a distorted picture of the average productivity, presented in appendix B. The average number of operators per day were 11.31, 14 and 9.8, respectively, for shelving, HOPT and reach truck. The average hours, lines and productivity are presented in table 1.

Table 1: Productivity at pick locations

Picking	**Avg. Hours**	**Avg. Lines**	**Avg. Productivity**
Shelving	6,27	143,41	23,21
HOPT	6,59	125,06	21,22
Reach truck	5,67	43,40	9,91

Looking at the average productivity at the pick area, it can be concluded that the average productivity is quite low compared to a regular warehouse. One of the reasons the average productivity is low is because 60.000 different items are stored in both areas. The high number of items results in long travel time between two pick assignments, increasing the pick time (Tompkins et al., 1996). Another reason is that pickers have to pick items in high storage locations. Picking in a high storage location in the shelving area requires climbing a ladder or travelling in the vertical direction with the HOPT. According to Petersen et al. (2005), these additional actions require extra time, which results in a decrease in the average pick productivity.

In addition, the difference between the average productivity of shelving and HOPT relative to reach truck can be explained by the fact that multiple items are picked per route in the shelving and HOPT area. In contrast, the reach truck can pick only one item per route due to the large size and high weight of the items. Picking multiple items in one route decreases the total travel distance as the picker does not have to travel to the drop off point every time after each pick (Shetty et al., 2020). The decrease in travel distance results in a higher average productivity.

After a picker has collected the item or items from one of the picking areas, the picker drops the item(s) at one of the four pack locations: Parcel, Rack, Large and Bypass. At these packing locations, the items either will be consolidated into one big carton or wooden package, or when it is one big item, it will be packed into a single package. The WMS determines what type and size box it needs to be packed. All the measurements of the items are known in the WMS. This allows the WMS to select a box where the empty space in the box is minimal. Minimising empty space saves money because the boxes take up less space in the truck. Besides, it saves cartons and wood, which is good for the environment.

Table 2: Average number of packages per day in October 2021

Pack location	**The average number of packages per day (Aug 2021)**
Bypass	277
Large	60
Parcel	240
Rack	171

The average productivity per pack location is presented in table 3. The average productivity is calculated with data of 29 days in October and November 2021. Outliers were removed from the data using a boxplot, presented in appendix C. The average number of resources per day were 7,06; 6,31; 2,75; and 1,8, respectively, for parcel, rack, large and bypass.

Table 3 shows that the productivity with large and rack is higher than with parcel and bypass. The main reason for the higher productivity at large and rack is that multiple items are packed into a package. Resulting in fewer boxes per hour but a higher number of lines per hour. Parcel and bypass mainly concern single item boxes, which means that the number of boxes per hour is higher, but the number of items per hour is lower.

Table 3: Productivity at pack locations

Pack location	**Ave. Hours**	**Ave. Lines**	**Ave. Productivity**
Parcel	6,44	92,49	19,12
Rack	6,35	165,89	40,05
Large	5,78	205,05	65,19
Bypass	6,01	117,94	19,36

After the packing process has been completed, the marshalling process starts with one of the two marshallers picking up a package from one of the packing locations. These marshallers use forklifts to transport a package to the staging lane area. To determine to which staging lane the package needs to go, the marshaller uses an RF-scanner. When the marshaller scans the package, the RF-scanner provides information on which staging lane the package should be transported.

On average, 741 packages have to be transported from the packing locations to the staging lanes. Table 4 presents the average number of packages per pack location per carrier. Most packages have to be transported from the parcel pack location to a staging lane. The fewest packages need to be picked up at large since the number of large products is relatively low compared to the number of smaller products. Besides, packing a large package with multiple items takes a lot longer than packing a small single item package.

Table 4: Average number of packages marshalled per carrier per pack location per day in October 2021

Carriers Pack location	**Aerocar**	**CEVA FM**	**DGF**	**DHL Exp.**	**Pick-up**	**Schenker**	**Seacon**	**TNT Exp.**
Bypass	44	16	138	3	5	57	3	16
Large	13	7	25	2	1	11	1	1
Parcel	71	7	98	3	7	14	1	46
Rack	48	13	70	3	6	33	3	1
Total	**175**	**43**	**331**	**11**	**19**	**115**	**8**	**64**

Table 5 presents the average distance in meters the marshallers need to travel per pack location per carrier. The two marshallers had to travel on average 53,25 kilometers (km) in the month of August from the pack location to the marshalling lane. The large packing location is located the furthest from the staging lanes as here the fewest packages need to be picked up. Besides, the large pack location is located close to the racking area as most of the items packed at large come from the racking area.

Bypass is located second furthest from the staging lanes but closest to the racking area. The main reason for this is that only products from the racking area are packed at this location. The rack location is located between the shelving and racking area because items are dropped off from both the shelving area and the racking area for packaging.

Finally, the parcel pack location is located the closest to the staging lanes, as many packages have to go to the staging lanes from this pack location. Besides, the parcel location is located close to the shelving area as almost all items picked in the shelving area are processed at the parcel pack location.

Table 5: Total distance travelled by marshaller per pack location per carrier in meters

Carriers Pack location	**Aerocar**	**CEVA FM**	**DGF**	**DHL Exp.**	**Pick-up**	**Schenker**	**Seacon**	**TNT Exp.**
Bypass	2008	1040	6513	160	325	1260	109	496
Large	997	665	1930	167	103	573	66	61
Parcel	7149	833	9917	322	170	1065	90	3910
Rack	4065	1339	5964	274	294	1983	223	69
Total	**14219**	**3877**	**24325**	**923**	**892**	**4881**	**488**	**4536**

The marshallers bring the packages to the staging lane. Staging is the short-term storage of packages. Therefore, staging is a buffer to consolidate all packages of one order. The use of staging lanes allows the picking and packing process to start earlier and spread the workload of these processes as they do not have to start just before the truck arrives. Another advantage of using staging lanes is that employees who load the trucks have a better view of the available freight for loading. A better view can lead to a tighter freight pack while loading, thus reducing transportation costs (Luo & Noble, 2012).

The staging lanes are located close to the outbound docks because the distance that the packages still have to travel is minimal. The staging lanes are now designed based on the carrier and the dock where the carrier is assigned to, as presented in figure 3. In the current layout, the staging area is divided into fifteen separate staging lanes.

In addition, carrier DGF has in total seven staging lanes based on country. These staging lanes are divided into seven staging lanes because certain countries had daily shipments a few years ago. The countries with daily shipments were given a dedicated staging lane. However, currently, these countries do not have daily shipments anymore. This separation makes collecting a DGF shipment more difficult because the packages are spread over multiple staging lanes.

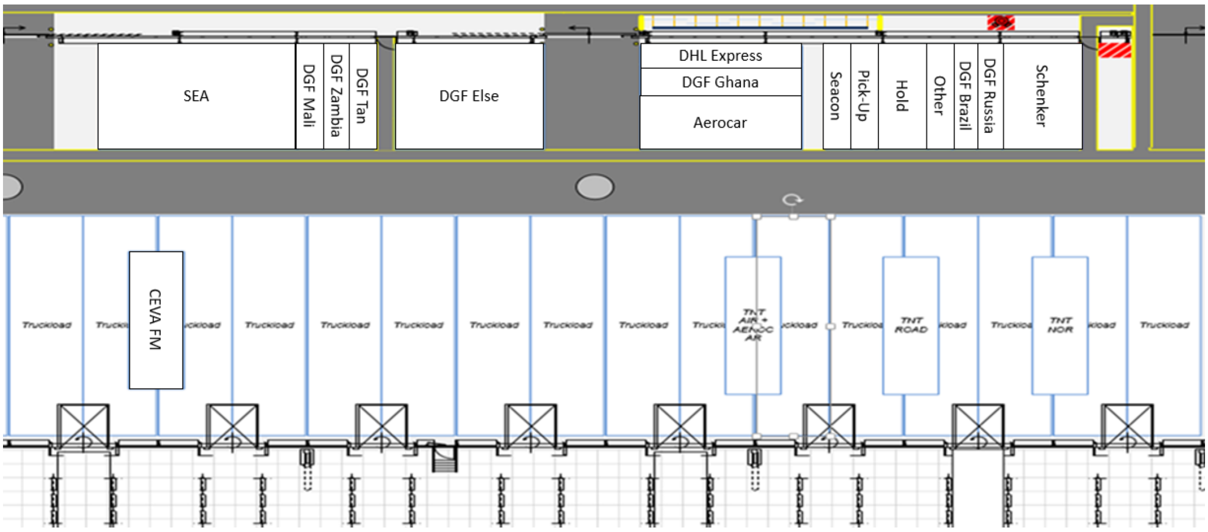

Figure 3: Current layout of expedition

The assignment of the packages to the staging lanes is done via the WMS. The WMS knows which carrier has to transport the package and will assign the package to the dedicated staging lane of that carrier. For example, when a marshaller picks up a package at pack location large, which belongs to a shipment of Aerocar. The RF-scanner, which is connected to the WMS, tells the marshaller to transport the package to the staging lane of Aerocar.

Nevertheless, it still happens every day that a staging lane is congested. The main reason for this is that the staging lanes have no limit on the number of packages that can be placed. The absence of a limit makes it possible for the WMS to assign packages to an already crowded staging lane. For example, when a shipment is delayed, and the next wave of orders for the same carrier is already released. The dedicated staging lane will be congested as two shipments exceed the capacity.

When all the packages have been packed and marshalled, the expedition employees receive a pre-manifest from the customer service department. With this pre-manifest, the employees of expedition start collecting all packages based on load IDs on the package label. Once all the packages on the pre-manifest have been located, the expedition employees can scan and move the packages to the dock.

If not, all packages can be found in the staging area. The expedition employees first need to check whether the package is already packed. If this is the case, the docking staff must first check whether the package is not in another location, for example, an adjacent staging lane. If the package is not found before the carrier arrives, the manifest with the missing package will be removed from the shipment, and the manifest will be shipped with the next shipment.

1.2 Scope and project goal

In this section, the scope will be introduced, and the goals of this research will be presented. The scope is summarised in table 6.

Table 6: Scope of thesis

Within scope	***Out of scope***
Shipments of Sandvik	Outbound shipment of other contracts
The layout of the staging lanes	SKU locations
Shipment assignment	Truck scheduling
Marshalling process	Pick and pack process
	Resource scheduling
	Stock levels
	Extra-large items

To gain a competitive advantage, fast and reliable delivery of the ordered products are two of the key factor to focus on (Viswanadham, 2000). Besides, fast and reliable delivery have a major impact on customer satisfaction (Kim, 2018). That is why all processes in a warehouse must be well-coordinated and function optimally. However, as stated in the introduction, this is not yet the case with the staging process.

Therefore, the goal of this thesis will be to optimise the staging process to the conditions in the CEVA Logistics warehouse. By looking into the staging area layout and the staging lane assignment. The improvement of the staging process will ultimately lead to a decrease in pick-to-ship cycle time. Resulting in more preparation time of the shipment for the employees of expedition. With the increase in preparation time, the expedition employees have more time to search for any missing packages, leading to a decrease in incomplete manifest.

1.3 Sub-questions and methodology

The main research question and the supporting sub-question will be introduced in this section. These questions will be based on the introduction section, research question and the process description. Given these sources of information, the following sub-questions will be investigated:

1. *What models for staging lane assignment problems can be found in existing literature?*

The second sub-question aims to get an overview of the existing literature on staging lanes assignment problems. The main focus will be on the mathematical models which solve the staging lane assignment problem or similar assignment problems. The databases used for this literature review are ProQuest, ScienceDirect and Google scholar.

2. *How can the layout of the current staging area be improved?*

A new layout for the staging area will be proposed in this question. For the new layout, the amount and capacity of the staging lanes and the allocation policy will be taken into account. The new layout will be based on scientific literature, warehouse management system (WMS) data, interviews with the supervisor of expedition, and available space for the staging lanes.

3. *What will be the optimal staging lanes schedule for the outgoing shipments of Sandvik?*

The purpose of this question is to optimise the assignment of shipments to the staging lanes with the layout and allocation policy found in the previous question. In this optimisation problem, the goal is to assign the packages of outgoing shipments to a staging lane in such a way that no staging lane gets congested and the travelling time from the packing location to the staging lane is minimised. This staging lane assignment problem will be programmed in Python using the Gurobi Optimizer.

To create this model, the restriction and scope have to be defined. When the problem and scope have been defined, input data will be collected from the WMS, management reports and measurements in the warehouse itself. After the input data has been collected, the model will be built based on the restriction and scope that have been defined.

1.4 Outline

In the first chapter, the company and problem are introduced, followed by the research question, which will be answered in the thesis. Afterwards, a detailed overview is provided of the current outbound process at the company. The research scope and sub-research questions are formulated based on the problem, research question, and process overview. In the second chapter, possible layouts and staging lane scheduling models will be introduced in this chapter. An overview of the existing literature on layouts and staging lane scheduling models are provided. With the results of this chapter, the first research question is answered. The third chapter provides a new layout of the staging area. The new layout will be based on literature, data from the WMS, accessibility of the staging lane, and distance travelling from the packing locations. The results of this chapter are used to answer the second research question. In the fourth chapter, a conceptual staging lane scheduling model will be introduced to optimise the assignment of shipments to the staging lanes. With the use of the conceptual model introduced in the fourth chapter, a case study is conducted to see what effect optimizing the staging lane schedule has on the staging process. In chapter six, the results of the case study are presented, followed by a sensitivity analysis and a discussion. In the last chapter, the research question is answered. Besides, the academic and practical relevance are highlighted. Finally, limitations and future research directions are discussed.

2. Literature review

This chapter provides a summary based on the literature review of Nijsten (2022). In this chapter, several topics within the scheduling research field will be reviewed. Firstly, the staging lane assignment problem will be reviewed. Secondly, various airport gate assignment problem (AGAP) models will be discussed. Finally, various berth assignment problem (BAP) models will be discussed. This literature review answers the first sub-question, providing academic approaches for scheduling problems, such as the staging lane assignment problem at CEVA Logistics.

2.1 Staging lane assignment problem

Looking into the research conducted on staging lane assignment problems in a warehouse, most published work is related to cross-dock warehouses (Gue & Kang, 2001; J. F. Wang, 2010; Luo, 2018). At cross-dock warehouses, packages are moved directly from receiving dock to the shipping dock with the goal to minimize the storage time of the package (Apte & Viswanathan, 2000). The staging lane problem can be divided into single-stage system and two-stage system problems, as presented in figure 4. A single-stage system has only one row of staging lanes in which the packages are staged. A two-stage system has two rows of staging lanes, as presented in figure 5.

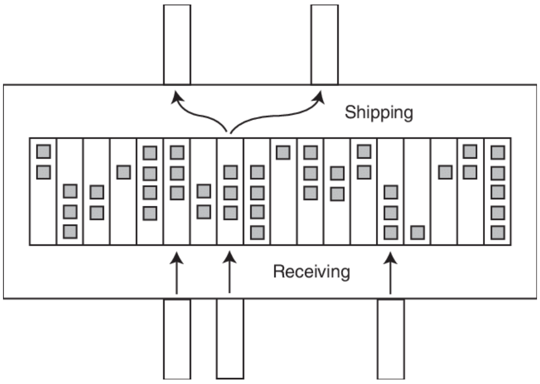

Figure 4: Single stage system (Bartholdi et al., 2007)

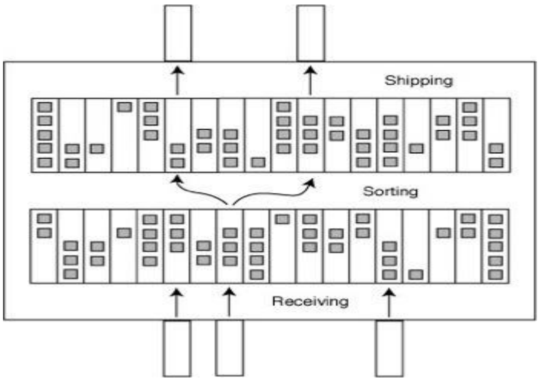

Figure 5: Two stage system (Bartholdi et al., 2007)

Bartholdi et al. (2007) look at different protocols for staging areas in cross-docking warehouse. The first staging protocol is “single-stage, sort-at-shipping”, in which workers unload a package from arriving truck and directly put the package in the receiving lane by the dock. On the other side of the staging lane, workers deliver the packages to the appropriate outbound truck (Gue & Kang, 2001). The advantage of the single-stage protocol is that workers do not have to check the destination of the package when the workers unload the truck as the shipping labels are applied to the packages after the packages have been put in the staging lane (Bartholdi et al., 2007).

Another protocol for a single-stage system is sort-at-receiving. With this protocol, workers unload a truck and put the package in the staging lane associated to the shipping dock (Bartholdi et al., 2007). The advantage of sort-at-receiving is that workers at the shipping dock have a good view of what freight is available for shipping. A good view of the available freight can lead to a tighter pack of freight while loading as the employees know what to load (Luo & Noble, 2012).

The two-stage system is divided into two sets of staging lanes: the receiving staging lanes and the shipping staging lanes. This two-stage system has the advantages of both the single-stage sort-at-shipping and sort-at-receiving, as the workers at the receiving dock do not have to check the destination of the package when the worker unloads the truck and workers at the shipping dock have a good view of what freight is available for shipping. However, Gue & Kang (2001) state that, despite the advantages, the two-stage system has a significantly lower throughput than the single-stage systems.

To minimize the storage time of the packages at the cross-dock locations, Zhu et al. (2009) presents a bilinear integer programming formulation of the Cross-dock door assignment problem (CDAP), which is an extension of the CDAP model of Tsui & Chang (1992). The goal of the model is to minimize the total distance travelled between the docks. In the model of Tsui & Chang (1992), they use as input parameters the number of receiving and shipping docks, number of origins and destinations, the distance between docks and number of trips needed to move the items from receiving to the shipping dock. Zhu et al. (2009) extended the model by adding constraints on the capacity of the staging lanes behind the receiving and shipping docks.

Nassief (2017) introduces a linear mixed integer programming (MIP) formulation for the CDAP. The linear MIP is formulated with Lagrangean relaxation due to the high number of variables and constraints. Nassief's (2017) computational results show that the linear MIP formulation has an efficient and scalable solution approach confirmed.

2.2 Gate assignment problem

The AGAP is a broad studied problem in the operational research field. The study of Braaksma & Shortreed (1971) was the first attempt to improve the utilisation of the gates at an airport. They constructed a simulation model based on the Critical Path Method.

The problem can be divided into static AGAP and stochastic and robust AGAP (Karsu et al., 2021). The static AGAP is formulated with a deterministic model that minimises ungated flights, walking distance, or waiting times. The stochastic and robust AGAP considers some stochastic aspects as a flight delay or early arrival. Commonly, the models aim to minimise flight delay and gate conflicts.

Both categories have been extensively studied in the literature. The small-scale AGAPs can be solved with an exact solution approach, such as binary integer programming, mixed integer programming, and mixed-integer linear programming. These approximations cannot be used for large-scale problems because the computation time increases rapidly as the number of integers grow (Yu et al., 2016). For the large scale AGAPs, heuristic algorithms are used to solve the problem, such as greedy algorithm, branch-and-bound and branch-and-trim.

The study of Babić et al. (1984) was one of the first studies aiming to minimise the passengers' walking distance. They formulated the AGAP deterministic as they did not take into account delays or other uncertainties. The method used to solve the problem was based on the branch-and-bound technique. However, they slightly adjusted it to improve the computational time. They assumed that passengers do not transit, and every plane will be assigned to a gate. The optimal solution found decreased the number of passengers who walked the maximum distance and increased the number of passengers who walked the minimal distance compared to the random gate assignment.

Mangoubi & Mathaisel (1985) study solved the AGAP with a linear programming relaxation and a greedy algorithm. The objective was to minimise the total walked distance of passengers in the terminal. They used data of an average day at Toronto airport to compare the result of their model. The optimal result of the linear programming reduced the total distance walked by 32 per cent.

AL-Sultan et al. (2011) introduce an algorithm to optimise the AGAP. They first introduced an algorithm that aims to minimise the total walking distance. In addition, they are introducing a greedy algorithm for minimising the number of flights not allocated to a gate. The algorithm is based on previous research by Ding et al. (2004), who designed a greedy algorithm and used a tabu search meta-heuristic to minimise ungated flights. Due to the size of the problem used in the study, a greedy algorithm is introduced. The greedy algorithm minimises the number of flights assigned to no gate. The results of the study show that the initial situation is improved from 212 in the incoming flights and 193 in the outgoing ungated to 85 for the incoming flights and 82 for the outgoing flights ungated. Besides, the walking costs are reduced by 16%. These results were obtained with a buffer time between flights of zero.

As presented in the previous sector, most deterministic models aim to minimise the total walked distance of the passengers. The solutions of these models often result in high utilisation of the gate closest and low utilisation of the furthest gate from the entrance/exit of the airport. A minor disruption in a flight at one of the high utilised gates can cause passenger congestion (Mangoubi & Mathaisel, 1985). Therefore, Mangoubi & Mathaisel (1985) and Hassounah & Steuart (1993) introduced buffer time between two flights on the same gate in their model to make the solution more robust.

In the study of Bolat (1999), a mathematical model is developed to assign planes to a gate with the minimum range of unutilised time periods. This goal is subjected to the service level offered to the passengers and utilisation of the airport staff. Secondly, the assignments created by the model should be able to absorb some minor changes in the flight schedule. Bolat (1999) introduces a branch-and-bound and branch-and-trim algorithm to improve the assignment of planes at Riyadh International Airport. Their results show that the branch-and-trim algorithm outperforms the currently used procedure. On average, the branch-and-trim algorithm produces solutions that result in 66,35% fewer towed planes and a reduction in the total number of ungated planes compared to the current procedure.

Yu et al. (2016) proposed three mathematical models to improve the robustness of the AGAP: a network flow model with a quadratic objective function. In addition, they introduce two mixed integer programming models with linearisation of the quadratic objective. The objective of these models was to minimise the number of tow actions, minimise conflicts in the gate assignment schedule and minimise the travelled distance of the passengers. The two MIPs were tested with the test data of the study of Ding et al. (2004). The results show that linearisation of the quadratic objective reduces the central processing unit (CPU) time. However, the solving efficiency of the AGAP with 30 flights and five gates is far from satisfactory in practical application. When the size of the AGAP grows even more significant, the CPU times become too large for practical applications. Therefore, Yu et al. (2016) proposed to use heuristics for practical application as the AGAPs of nowadays are too large to solve in an acceptable time.

2.3 Berth assignment problem

The berth allocation problem (BAP) has been a widely studied problem over the last few years. In the BAP, a berth layout is given together with a set of ships that needs to be serviced within a specific time horizon. Each ship has data such as length, depth, expected arrival time and projected handling time. To solve the BAP, every ship has to be moored within the borders of the quay and the ships are not allowed to be assigned to the same berth within the same timeframe. The goal of the BAP is to ensure that all arriving ships are assigned to a berthing position and a berthing time within the given time horizon. The BAP has been proven to be an NP-complete problem (Lim, 1998). Therefore, large, real-world problems are solved using heuristic approaches due to the long CPU times (Lin et al., 2018).

The BAP can have several different constraints. One of these constraints is the layout constraints (Bierwirth & Meisel, 2010). The layout constraints can be divided in:

- Discrete layout: The quay is divided into several berths. A single ship can be served at a single berth at a particular time. Two examples are presented in figures 6a and 6b
- Continuous layout: The quay is not divided into berths, as presented in figure 6c. Ships can be assigned to each part of the quay as long as it is within the boundaries. The berth planning with a continuous layout is more complicated as the ships do not have fixed boundaries as in the discrete layout. However, the continuous layout is likely to have a better space utilisation.

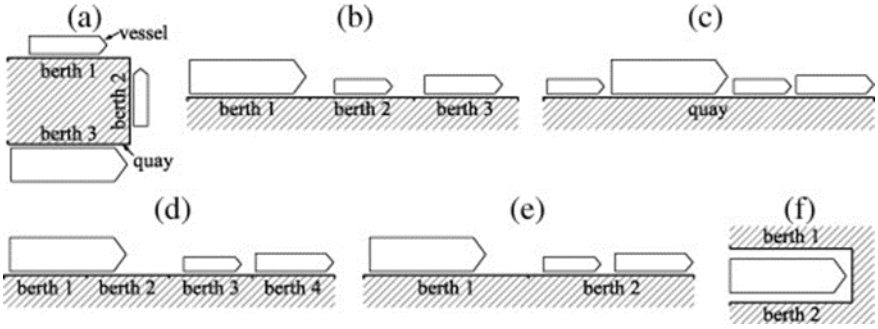

Figure 6: Different berth layouts (Bierwirth & Meisel, 2010)

Another constraint for the BAP is restricting ships' arrival and departure times. Imai et al. (2001) state that the following constraints can be distinguished:

- Static arrival times: In this case, the ships do not have a fixed arrival time. The first studies concerning this constraint assumed that ships already were waiting at the port. Therefore, ships were able to moor immediately when a berth became available. This assumption has been removed over the years. Now, the assumption is that ships can speed up to arrive earlier when a berth is already available. However, this will have additional costs.
- Dynamic arrival times: All the arriving ships have fixed arrival times. On the other hand, a ship cannot arrive earlier than the fixed arrival time.

2.3.1 Discrete berth assignment problem

One of the first studies on discrete static BAP (DSBAP) was conducted by Imai et al. (1997). In this study, an exact algorithm is introduced with the objective to minimise the time ships spend in the port. Besides, the dissatisfaction of berthing order is minimised. A couple of years later, Imai et al. (2001) solved the discrete static BAP using Lagrangean relaxation-based heuristic. The objective of this heuristic was to minimise the waiting and handling time of the ships. Afterwards, Hansen & Oğuz (2003) provided a MIP formulation with the same objective. To make sure every ship is handled and is not assigned to the same berth, they introduced the following constraints:

$i\ (1, \dots, I) \in B = \text{Set of berths}$

$j\ (1, \dots, I) \in V = \text{Set of ships}$

$k\ (1, \dots, I) \in O = \text{Set of service orders}$

$$x_{i,j,k} = \begin{cases} 1, \text{if ship } j \text{ is serviced as the } k\text{th ship at berth } i \\ \qquad 0, \text{otherwise} \end{cases}$$

$$\sum_{i \in B} \sum_{k \in O} x_{i,j,k} = 1, \ \forall j \in V \tag{1}$$

$$\sum_{j \in V} x_{i,j,k} \leq 1, \ \forall i \in B, \ \ k \in O \tag{2}$$

Constraint (1) ensures that every ship is served at a berth. Constraint (2) ensures that a berth can only service one ship at any time.

The main difference between the static and dynamic problem is that ships are arriving as ships are being serviced, which is not possible in the static problem. Imai et al. (2001) proposed a model with the objective to minimise the total waiting and handling time for all the arriving ships. A heuristic is proposed based on the Lagrangian relaxation to solve this problem within a considerable CPU time.

In the study of Ting et al. (2014), a MIP model is proposed to solve the same problem. The model is able to solve up to 35 ships and ten berths. However, real-world problems usually are much larger. Therefore, they also propose an algorithm based on the particle swarm optimisation approach. The results show that the solution's quality and the proposed algorithm's CPU time are better than comparable algorithms.

Hansen et al. (2008) proposed a variable neighbourhood search heuristic. The objective of this heuristic is to minimise the handling times and service costs depending on the berth. The service cost are based on penalty costs when a ship departs too late and benefits from early departure. This heuristic outperforms Multi-Start, a Genetic Search algorithm, and a Memetic Search algorithm.

2.3.2 Continuous berth assignment problem

The continuous static BAP is the same as the discrete static BAP with the difference that the quay is not divided into berths. Ships can be assigned to each part of the quay as long as it is within the boundaries. Li et al. (1998) was one of the first studies conducted on the continuous static BAP (CSBAP). In their study, they solve the CSBAP by modelling the ships as jobs and the berth as a processor. Modelling the ships as jobs made it possible to solve the CSBAP as a "multiple-job-on-one-processor" scheduling problem. The objective of Li et al. (1998) was to minimise the makespan of the schedule by applying the First-Fit Decreasing heuristic, which resulted in near-optimal solutions.

In the study of Guan & Cheung (2004), a continuous dynamic berth allocation problem is solved with the objective to minimise the total flow time. In their study, they propose two mathematical models. The first model was used to create a tree search procedure. The second model was used to set a lower bound for the tree search procedure. The two models were able to generate exact solutions and outperformed the direct application of CPLEX.

F. Wang & Lim (2007) created a stochastic beam search algorithm with the objective to minimise the penalty cost and apart berthing. The penalty costs are added when a ship is rejected. The algorithm is able to solve continuous dynamic BAPs up to 400 ships.

Zhen & Chang (2012) aim to create a robust allocation schedule that considers uncertainties such as ships arriving too early or too late. They proposed a bi-objective optimisation model to minimise the total costs and maximise the robustness of the allocation schedule. However, the bi-objective model is not able to solve large-scale problems within a reasonable CPU time. Therefore, a heuristic is proposed for large-scale problems.

3. The layout of the staging area

In this chapter, the layout of the future staging area will be determined. First, the current situation will be reviewed based on the capacity and the allocation policy. Secondly, a new layout will be proposed based on scientific literature and historical data. Besides, the accessibility of the staging lane and distance travelling from the packing stations will be considered.

3.1 Current layout of the staging area

The current layout is based on shipment volumes of around five years ago. As presented in table 7, the staging lanes have a fixed capacity. For example, DGF Else has a staging capacity of 147 m^3 since DGF has multiple shipments a day. The staging lanes of DGF Mali and DGF Tanzania are relatively small, both 29,4 m^3, as these countries typically have a relatively small shipment. Besides, CEVA FM and TNT are currently directly staging at the dock.

Table 7: Current capacity of the staging lanes

Carrier	**Current capacity (m^3)**
Aerocar	78
CEVA FM	Dock
DGF-Brazil	37,8
DGF-Else	147
DGF-Ghana	39
DGF-Mali	29,4
DGF-Russia	37,8
DGF-Tanzania	29,4
DGF-Zambia	29,4
DHL-Express	19,5
Other	37,8
Pick-up	39,9
Schenker	109,2
Seacon	33,6
TNT	Dock
Sea	189,2

In addition, looking at the layout presented in figure 7, CEVA Logistics uses the staging protocol single-stage sort-at-receiving for most carriers. For example, the packages for Schenker come from different pack locations and are consolidated at the staging lane dedicated to Schenker. However, for DGF, CEVA Logistics uses a combination of sort-at-receiving and sort-at-shipping as DGF has several small staging lanes assigned to different countries, such as Mali, Zambia, Tanzania, Brazil and Russia. First, packages are sorted and consolidated at the staging dedicated to that country. After that, the packages are re-sorted to load them into the correct truck. The combination of staging protocols makes it difficult and time-consuming for the expedition personnel to collect all the packages because it often happens that packages are spread over the different staging lanes of DGF.

Finally, the staging lanes are all dedicated to either a carrier or a carrier and a country, as presented in figure 7. These two pack locations are the furthest from the staging lane, requiring the marshaller to travel a long distance to get all the packs to the staging lane. However, with the use of dedicated staging lanes, the distance the marshallers have to travel to bring packages from the pack locations to the staging lanes is not taken into account. For example, DGF Else has, on average, a relatively large number of packages from large and bypass.

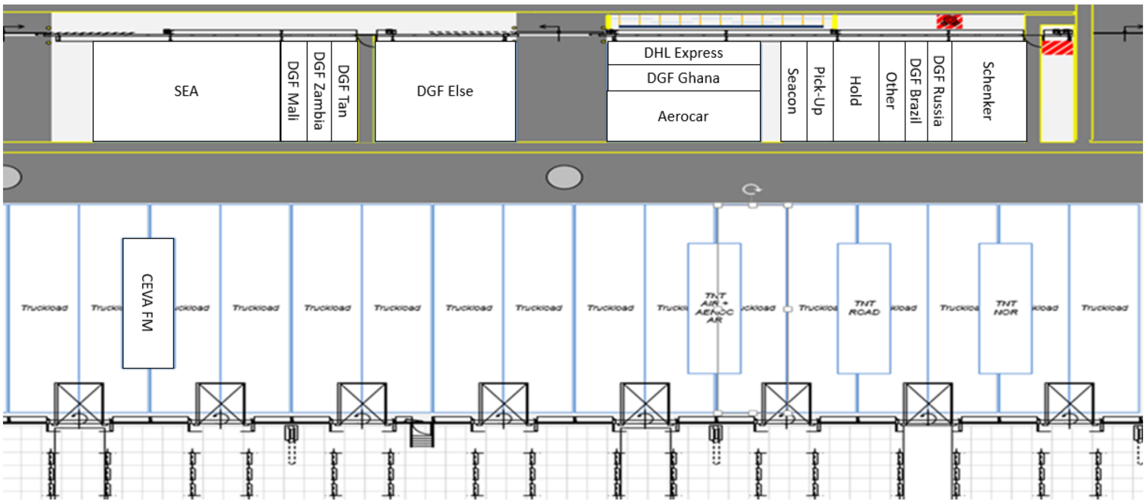

Figure 7: Current layout of the staging area

3.2 Allocation policy

For the new layout, a new allocation policy will first be looked at because the current dedicated allocation policy causes unnecessarily long loading times because packages are assigned to multiple staging lanes.

Various allocation policies can be found in the literature, such as random allocation, where shipments are randomly assigned to one of the free staging lanes in the staging area. With random allocation, all free staging lanes have an equal chance of being selected. This allocation policy has as advantage that it has a high utilisation rate. However, the total marshall distance likely increases because the distance between the 'filled' staging lanes is not considered (Sharp et al., 1991).

Another allocation policy is dynamic allocation. Dynamic allocation aims to make the staging area small by assigning items just in time to free locations. By doing this, the number of storage locations can be smaller than the number of shipments in the staging area. This allocation policy aims can also be used to minimise the total distance travelled by marshallers (de Koster et al., 2007).

As the staging area has limited space, the most suitable allocation policy would be the dynamic allocation policy, which minimises the needed space (de Koster et al., 2007). In addition, with the dynamic allocation policy, it is also possible to minimise the distance for the marshallers by assigning large shipments to staging lanes closest to the pack locations and assigning the smaller shipments to staging lanes further from the pack locations.

In addition, the implementation of the dynamic staging policy ensures that CEVA Logistics only uses a single staging protocol, namely the sort-at-receiving. Using sort-at-receiving makes it easier for employees of expedition to find the right packages

However, currently, the WMS is not able to dynamically assign shipments based on the minimum distance that the marshaller must travel. To make it possible for the WMS to assign shipments to a staging lane dynamically, some IT changes need to be made in the WMS. First, the old staging lanes have to be removed, and the new staging lanes have to be added to the WMS. Secondly, the allocation policy has to be implemented into the system to make sure the total distance the marshaller has to travel is minimized. The last IT change in the WMS is the ability to scan packages from the staging lane to the issue lane and the other way around.

3.3 Capacity of the staging lanes

The capacity of the staging lanes will be determined based on the shipment volume of the month of November 2021, as this month has no holidays, which could have an influence on the volume of the shipments. Besides, CEVA Logistics implemented a new warehouse management system (WMS) in April 2021. The implementation of the new WMS has caused some disruption in the number of shipped items in the months after the release.

Table 8: Average and maximum volume per carrier in m3

Carriers	**Average Volume (m^3)**	**Max of Volume (m^3)**
AEROCAR	21,58	33,08
CEVAFM	24,67	40,54
DGF 1	20,20	52,06
DGF 2	18,16	35,46
DGF 3	9,54	33,85
DGF 4	27,60	38,52
DHL	0,19	0,80
SCHENKER	20,56	37,23
SCHENKER 2	23,76	36,63
SEA	23,39	38,94
SEACON	9,05	25,54
TNT	5,22	14,45
Pick-up	5,21	14,59

As presented in table 8, most carriers have an average volume between twenty and twenty-five cubic meters (m^3), and four carriers have an average volume below ten cubic meters.

However, to determine the capacity of the staging lanes, the maximum volume must be considered because the volume of the shipments may not exceed the capacity of the staging lane. Exceeding the capacity of the staging lane causes congestion which increases the probability of packages not being located, resulting in packages being dropped out of the shipment (Van Niekerk, 2017). Lost packages contribute to excessive shipment loading times as loading staff has to spend much time locating the packages, reducing the loading efficiency (Van Niekerk, 2017).

Besides, the accessibility of the staging lanes must also be considered. In this context, accessibility refers to the difficulty of reaching packages in the staging lane. For example, suppose the capacity of a staging lane is 20 m^3, and the volume of a shipment is equal to 18 m^3. In that case, the accessibility is smaller than if the staging lane has a capacity of 40 m^3 for the same shipment. Therefore, when creating the new layout for the staging area, it was taken into account that the capacity of the staging lanes has to exceed the maximum volumes of the carriers.

Finally, to determine the number of staging lanes, the number of arriving trucks per day must be considered. In the new layout, there must be at least as many staging lanes available as trucks are arriving since there is a possibility that all these trucks will pick up the shipment around the same time. This chance is very small in reality, but it must be considered when creating a new layout.

In addition, there is a chance that packages will be lost during the pick or pack process. As a result, a manifest cannot be loaded into the truck as an incomplete manifest cannot be shipped out. The packages of the incomplete manifest then remain in the staging lane. The problem then arises is that another shipment may be assigned to this staging lane. To solve this problem, an issue staging lane(s) will be added when the new layout is created. The issue lane is created to temporarily store packages from incomplete manifests until the missing package is found or re-picked and repacked.

3.4 New layout of the staging area

Based on the requirements from the previous section, a new layout has been made for the staging area, as presented in figure 8. With the new layout, it was determined to give the first five staging lanes the largest capacity, 60,8 m^3, because the shipments with the highest volumes have the highest probability of receiving a large number of packages, which means the marshaller is likely to have to travel greater distances.

In addition, it has been decided to rotate staging lanes six and seven a quarter of a turn compared to the first five staging lanes. This choice was made because a higher number of staging lanes can be fit into the available space, and both staging lanes at this location are easily accessible for MHEs.

Staging lanes eight through thirteen are again situated in the longitudinal direction. Staging lanes eight and nine have a smaller capacity than the first five staging lanes, 53.2 m^3, but still have enough capacity to have good accessibility. Staging lanes ten through thirteen are again somewhat smaller than staging lanes eight and nine because the shipments with the smallest volumes have the highest chance of receiving a small number of packages, so there is a good chance that the marshaller has to travel shorter distances.

Finally, staging lanes fourteen and fifteen have the smallest capacity. Staging lane fifteen will serve as an issue lane in this new layout. Whether staging lane fourteen will act as a staging lane or as an issue lane will depend on the staging lane schedule. If no shipments are assigned to this staging lane, it will serve as an issue lane; if this is not the case, staging lane fourteen will serve as the staging lane.

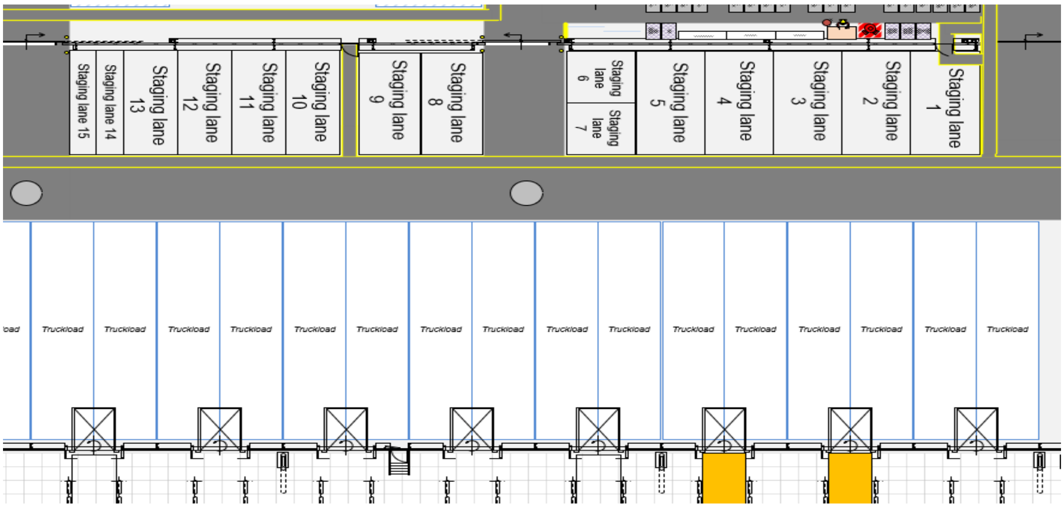

Figure 8: New layout of the staging area

4. Conceptual model: staging lane assignment problem

In this chapter, a conceptual model will be proposed. First, the assumptions made with this model will be presented. Afterwards, different sets, parameters and decision variables will be presented. With the help of the proposed sets, parameters and decision variables, the objective and the constraints will be created with the goal to optimise the assignment for the staging lanes. Finally, the experimental settings will be explained.

4.1 Assumptions

While creating the model, several assumptions have to be made. The first assumption regards the release and departure times of the vehicles. These times are assumed to be fixed. Fixed release and departure times mean that when a truck is scheduled to depart at 14:00, the truck will depart at 14:00. Delays, such as traffic jams or accidents, will not be considered. The same holds for arriving too early. The truck will not be serviced earlier when it arrives 15 minutes too early. In addition, minimal slack time will be added to the model between two assignments of vehicles to a certain staging lane. Minimal slack time can be seen as a time buffer that is able to absorb potential delays in the schedule (Lambrechts et al., 2011).

The second assumption regards the time a vehicle is assigned to a staging lane. A vehicle will occupy a staging lane from the moment the vehicle is released. This means that there will be a possibility that in the beginning, the staging lane will be empty because the items need to be picked, packed and marshalled first. However, it cannot be determined when the first package arrives at the staging lane because the pick and pack process is not considered in this model. Besides, it can happen that one or multiple packages did not go with the vehicle of the same carrier the day before. These packages are already picked, packed and marshalled and will be added to today's vehicle. These packages only have to be transported from an issue area to the assigned staging lane. Therefore, a vehicle will occupy the staging lane from the moment it is released.

The third assumption regards the availability of the items on stock. In this model, it will be assumed that all products in a released vehicle will be on stock. This means that the released volume will be the same as the shipped volume.

The fourth assumption is that a marshaller only takes one package at a time. In this model, it will be assumed that a marshaller can only take one package each time the marshaller travels from the pack location to the staging lane. This assumption is made as it is out of scope in which sequence the packages are released at the pack location. Besides, the volume of a single package is unknown, making it impossible to determine how many packages can be transported in one trip to the staging area.

4.2 Sets and parameters

First, a set of vehicles will be introduced. A vehicle consists of a set of items that will be transported by a carrier. As explained in chapter three, the set of items will be picked in the different areas. Afterwards, the products will be packed at one of the four pack stations. This shipment will be transported to its destination by a particular carrier. In the case of CEVA Logistics, there are eight different carriers. Some carriers send only one vehicle a day; other carriers have multiple vehicles a day.

$n = total\ number\ of\ vehicles$

$I \epsilon \{1,2, \ldots\ldots, n\}$

The second set (Set P) consists of the pack locations in the warehouse of CEVA Logistics. As mentioned in chapter three, CEVA Logistics has four different pack locations to pack the items that need to be shipped out.

$w = total\ number\ of\ pack\ locations$

$P \epsilon \{1,2, \ldots\ldots, w\}$

The third set (Set J) consists of the staging lanes in the outbound area of CEVA Logistics. As mentioned in chapter five, CEVA Logistics has a fixed number of staging lanes with a fixed capacity. A single staging lane can handle multiple shipments a day as long as the shipments do not overlap each other.

$m = total\ number\ of\ staging\ lanes$

$J \epsilon \{1,2, \ldots\ldots, m\}$

The fourth set (Set T), presented in table 10, consists of all time frames in which the warehouse is operational. These time frames are introduced to show in which time frames a shipment is assigned to a certain staging lane.

$q = total\ number\ of\ time\ frame$

$T \epsilon \{1,2, \ldots\ldots, q\}$

The fifth set (Set D) consists of the departure times of the vehicles. As mentioned in the assumptions, these arrival times are fixed and, therefore, will not be changed during the calculation of the model.

$dt_i = departure\ time\ of\ vehicle\ i$

$D \epsilon \{dt_1, dt_2, \ldots, dt_n)$

The sixth set (Set R) consists of the release times of the vehicle to start the picking process. As mentioned in the first chapter, the release times are fixed and, therefore, will not be changed during the calculation of the model.

$rt_i = release\ time\ of\ vehicle\ i$

$R \epsilon \{rt_1, rt_2, \ldots, rt_n)$

Besides creating the mathematical model, several parameters will be introduced. These parameters will be based on historical data of the WMS, measurements, and information from the carriers. First, the distance matrix, $d_{p,j}$ is introduced. This distance matrix consists of the distance it takes to travel from pack location *p* to staging lane *j.* Secondly, the parameter $np_{i,p}$ will be introduced. $np_{i,p}$ represents the number of packages for vehicle *i* packed at pack location *p*. These packages will be marshalled to the staging lane with a forklift from the pack location. This forklift travels from the pack location to the staging lane with an average speed of *a*.

$d_{p,j} = Distance\ from\ pack\ location\ p\ to\ staging\ lane\ j\ (m)$

$np_{i,p} = Number\ of\ package\ for\ vehicle\ i\ packed\ at\ pack\ location\ p$

$a\ = average\ speed\ of\ forklift\ (m/s)$

The time it takes to marshall all items from the pack locations to the assigned staging lanes will be represented by the matrix $m_{i,j}$. $m_{i,j}$ depends on the distance matrix $d_{i,j}$, number of packages for vehicle *i* packed on pack location *p*, $np_{i,p}$, and the average speed of the forklift, *a*. $m_{i,j}$ can be calculated with formula (3).

$$m_{i,j} = \sum_{p \in P} (d_{p,j} * np_{i,p}) * 2/a \tag{3}$$

First, distance matrix $d_{i,j}$ is multiplied by $np_{i,p}$. This results in the total distance the marshaller needs to travel to marshall the packages from the pack location to the staging lane. However, the marshaller also needs to travel back to the pack location to pick up the next package. Therefore, the first term will be multiplied by 2 to make it a two-way trip. To calculate the total time the marshaller spends on bringing the packages to staging lane *j.* The total distance to marshall all the packages of vehicle *i* to staging lane *j* will be divided by the average forklift speed *a.* For example, as $d_{1,1}$ is equal to 40 meters, $d_{2,1}$ is equal to 30 meters, $np_{1,1}$ is equal to 5, $np_{1,2}$ is equal to 3, and *a* is equal to 5 meters per second. This results in the total marshalling time for $m_{1,1}$ of 116 seconds.

Besides, some parameters are introduced for the staging lanes. First, the volume of vehicle *i* is introduced. This volume of the vehicle is determined by the sum of the volumes of all the items. The vehicle's volume will be used to determine to which staging lane the shipment is assigned as the volume of the vehicle cannot exceed the capacity of the staging lane. This increases the chance on long collecting times and missing packages. Secondly C_j, which presents the capacity of staging lane *j*. The capacity is based on the staging lanes' width, length, and stacking height. The width and length of every staging lane will be measured, and the maximum stacking height within the staging lane is two meters. Finally, parameter ST is introduced. ST represents the minimal slack time between to assignment of vehicles. Minimal slack time is introduced to make sure a small vehicle delay will not cause problems in the staging lane.

$v_i = Volume\ of\ vehicle\ i\ (m^3)$

$C_j = Capacity\ of\ staging\ lane\ j\ (m^3)$

$ST = minimal\ slack\ time\ between\ two\ assignment\ of\ vehicle\ to\ a\ staging\ lane\ in\ minutes$

4.3 Decision variables

Decision variable $x_{i,j,t}$ represents the decision of whether a vehicle is assigned to a certain staging lane at a certain time. If vehicle *i* is assigned to staging lane j at time t, $x_{i,j,t}$ becomes 1. If this is not the case, $x_{i,j,t}$ becomes 0. The vehicle, staging lanes and time for this decision variable come from set I, set J and set T introduced in the previous section.

$$x_{i,j,t} = \begin{cases} 1, if\ vehicle\ i\ is\ assigned\ to\ staging\ lane\ j\ at\ time\ t \\ 0, otherwise \end{cases}$$

Decision variable $y_{i,j}$ represents the decision of whether a vehicle is assigned to a certain staging lane. For example, if vehicle 1 is assigned to staging lane 3, $y_{1,3}$ is equal to 1. If this is not the case, $y_{i,j}$ is equal to 0. The vehicle, staging lanes and time for this decision variable come from set I, set J and set T introduced in the previous section.

$$y_{i,j} = \begin{cases} 1, if\ vehicle\ i\ is\ assigned\ to\ staging\ lane\ j \\ 0, otherwise \end{cases}$$

Decision variable $s_{i,j,t}$ and $e_{i,j,t}$ represent the release and departure time of the assignment of a vehicle to a staging lane. When vehicle *i* is assigned to staging lane *j* with a release time *t,* decision variable $s_{i,j,t}$ will be equal to 1. In all the other cases for this vehicle *i*, $s_{i,j,t}$ becomes 0. The same holds for $e_{i,j,t}$, but then for the departure time of the assignment of vehicle *i* to a staging lane *j* at time *t*.

$$s_{i,j,t} = \begin{cases} 1, if\ t\ is\ release\ time\ of\ vehicle\ i\ assigned\ to\ staging\ lane\ j \\ 0, otherwise \end{cases}$$

$$e_{i,j,t} = \begin{cases} 1, if\ t\ is\ departure\ time\ of\ vehicle\ i\ assigned\ to\ staging\ lane\ j \\ 0, otherwise \end{cases}$$

4.4 Mathematical model

The mathematical model is created based on the previous sections' introduced parameters and decision variables.

4.4.1 Objective function

The goal of the mathematical model is to minimise the total marshalling time. The total marshalling time depends on which staging lane a shipment is assigned to and the associated marshalling time. This results in the objective function (4) presented below.

$$min. \sum_{i \in I} \sum_{j \in J} y_{i,j} * m_{i,j} \tag{4}$$

4.4.2 Constraints

Constraint (5) ensure that only one vehicle *i* can be assigned to staging lane *j* at any time *t.* For example, when vehicle 1 is assigned to staging lane 1 at timeframe 1; $x_{1,1,1}$ is equal to 1. Constraint (5) ensures that it is not possible for other vehicles to be assigned to staging lane 1 at time frame 1. This constraint has been created because assigning multiple vehicles to one staging lane at the same time frame can result in an increase in loading time as the employee who is loading the vehicle has to search for the correct packages for that vehicle.

$$\sum_{i \in I} x_{i,j,t} = 1, \qquad \forall j \in J, t \in T \tag{5}$$

Constraints (6) and (7) define variable $s_{i,j,t}$ and $e_{i,j,t}$.

$$x_{i,j,t} - x_{i,j,t-1} = s_{i,j,t}, \quad \forall\, i \in I, j \in J, t \in T \tag{6}$$

$$x_{i,j,t} - x_{i,j,t+1} = e_{i,j,t}, \quad \forall\, i \in I, j \in J, t \in T \tag{7}$$

Constraint (8) ensures that vehicle *i* can only be staged in one staging lane. For example, when vehicle 1 is assigned to staging lane 1, vehicle 1 cannot be switched to another staging lane. Constraint (8) has been created to guarantee that a vehicle cannot be transported to another staging lane during the staging process. The additional transportation will increase the occupation time of the vehicle at the staging lanes and increase the chance of missing packages due to handling mistakes.

$$\sum_{t \in T} s_{i,j,t} - \sum_{t \in T} e_{i,j,t} = 0, \qquad \forall i \in I, j \in J \tag{8}$$

Constraint (9) guarantees that the volume of vehicle i does not exceed the capacity of staging lane j. For example, when vehicle 1 has a volume of 50 m^3 and staging lanes 1 and 2 have a capacity of 30 m^3 and 60 m^3. Vehicle 1 can only be assigned to staging lane 2, as the capacity of staging lane 2 is larger than the volume of vehicle 1. This constraint has been created to prevent packages from being stacked too high or next to the staging lane because this can result in an increase in loading time.

$$x_{i,j,t} * v_i \le C_j, \quad \forall\, i \in I, j \in J, t \in T \tag{9}$$

Constraints (10) and (11) guarantee that every vehicle *i* can only have one release and one departure time of the assignment to a staging lane. Constraints (10) and (11) have been created to ensure that there are no breaks in the assignment of a vehicle to a staging lane.

$$\sum_{i \in I} s_{i,j,t} = 1, \qquad \forall j \in J, t \in T \tag{10}$$

$$\sum_{i \in I} e_{i,j,t} = 1, \qquad \forall j \in J, t \in T \tag{11}$$

Constraint (12) makes sure that vehicle *i* is assigned to staging lane *j* until the departure time of vehicle *i*. For example, when vehicle 1 has to depart at time frame 6. The staging lane to which vehicle 1 is assigned to will be released at time frame 6 as vehicle 1 departures. Constraint (12) has been created to ensure that a vehicle is no longer assigned to a staging lane as it has been loaded into the vehicle.

$$\sum_{j \in J} e_{i,j,t} = 1, \qquad \forall\ (i,t) \in D \tag{12}$$

Constraint (13) makes sure that vehicle *i* is assigned to staging lane *j* from the release time of vehicle *i*. For example, when vehicle 1 is released at time frame 2. The staging lane to which vehicle 1 is assigned to will be occupied from time frame 2 until vehicle 1 departures. Constraint (13) has been created to ensure that a vehicle is assigned to a staging lane as it is processed.

$$\sum_{j \in J} s_{i,j,t} = 1, \qquad \forall\ (i,t) \in R \tag{13}$$

Constraint (14) ensures that the minimal slack time between two assigned vehicles to a certain staging lane is equal or larger than ST. For example, when ST is equal to 90 minutes (three time frames) and vehicle 1 departs at time frame 6. The staging lane to which vehicle 1 is assigned to will be released at time frame 6 as vehicle 1 departures. Then after 90 minutes, the next vehicle can be assigned to the staging lane in time 10.

$$\sum_{i \in I} e_{i,j,t} + \sum_{s=1}^{ST} s_{i,j,t+s} \leq 1, \qquad \forall j \in J, t \in T \tag{14}$$

Constraints (15) and (16) define decision variable $y_{i,j}$. These constraints ensure that $y_{i,j}$ turns 1 when the sum of $x_{i,j,t}$ over $t \in T$ is greater than 0 by multiplying $y_{i,j}$ and $(1 - y_{i,j})$ by M. M represents a large enough value that ensures that the constraint works as intended. In this model, M can be determined based on the number of time frames in T. M needs to have a larger value than the number of time frames in T. For example, when vehicle 1 is assigned to staging lane 1 at timeframe 1, 2 and 3. The sum of $x_{1,1,t}$ over $t \in T$ is equal to 3, ensuring that $y_{1,1}$ is equal to 1

$$\sum_{t \in T} x_{i,j,t} \geq M(1 - y_{i,j}), \qquad \forall i \in I, j \in J \tag{15}$$

$$\sum_{t \in T} x_{i,j,t} \leq M * y_{i,j}, \qquad \forall i \in I, j \in J \tag{16}$$

Constraint (17), (18), (19) and (20) ensure that decision variable $x_{i,j,t}$, $s_{i,j,t}$, $e_{i,j,t}$ and $y_{i,j}$ can only take values 0 and 1.

$$x_{i,j,t} \in \{0,1\} \tag{17}$$

$$s_{i,j,t} \in \{0,1\} \tag{18}$$

$$e_{i,j,t} \in \{0,1\} \tag{19}$$

$$y_{i,j} \in \{0,1\} \tag{20}$$

5. Case study: Shipments of Sandvik

In this chapter, the conceptual model from the previous chapter will be used to create a schedule for the vehicles of Sandvik in the staging lanes of CEVA Logistics. In the first section of this chapter, the sets and input parameters will be discussed. With the results of the model, the sub-question: "*What will be the optimal staging lanes schedule for the outgoing shipments of Sandvik?*" will be answered.

5.1 Input sets and parameters

5.1.1 Sets

As mentioned in the previous chapter, Set I, presented in table 9, consist of vehicles that arrive at the warehouse of CEVA Logistics to pick up outgoing shipments. Set I contain all the vehicles that arrived daily in the month of November 2021, as this month has no holidays or public holidays, which could reduce the number of items shipped or productivity. In this month, thirteen vehicles from nine different carriers arrived daily to pick up outgoing shipments.

Table 9: Set of arriving vehicle

i	Vehicle	i	Vehicle
1	Schenker	*8*	TNT
2	Schenker	*9*	SEA
3	CEVA FM	*10*	Pick up
4	DGF 1	*11*	Aerocar
5	DGF 2	*12*	Seacon
6	DGF 3	*13*	DHL Express
7	DGF 4		

Secondly, Set P, presented in table 10, contains all the pack locations in the warehouse of CEVA Logistics. The number of pack locations is equal to four: Pack, Rack, Large and Bypass.

Table 10: Set of pack locations

p	Pack location
1	Parcel
2	Rack
3	Large
4	Bypass

Set J contains all the staging lanes in the warehouse of CEVA Logistics, as presented in table 11. The number of staging lanes is equal to the number of staging lanes in the new layout, as presented in chapter three. In this set J, the issue staging lane is not taken into account as this staging lane only serves as a buffer to store manifests with lost or missing items temporarily.

Table 11: Set of staging lanes

j	Staging lane	j	Staging lane
1	Staging lane 1	*8*	Staging lane 8
2	Staging lane 2	*9*	Staging lane 9
3	Staging lane 3	*10*	Staging lane 10
4	Staging lane 4	*11*	Staging lane 11
5	Staging lane 5	*12*	Staging lane 12
6	Staging lane 6	*13*	Staging lane 13
7	Staging lane 7	*14*	Staging lane 14

Set T consist of the timeframe in which the warehouse of CEVA Logistics is operational, as presented in table 12. These time frames are introduced to show in which time frames a vehicle is assigned to a certain staging lane. In this case, half-hour time frames have been chosen because the vehicles arriving at the dock on full or half-hour. The warehouse of CEVA Logistics is operational from 05:30 until 0:00 on a regular weekday. Therefore, there will be 38 time frames.

Table 12: Set of operational time frames

t	Time	t	Time	t	Time	t	Time
1	05:30	*11*	10:30	*21*	15:30	*31*	20:30
2	06:00	*12*	11:00	*22*	16:00	*32*	21:00
3	06:30	*13*	11:30	*23*	16:30	*33*	21:30
4	07:00	*14*	12:00	*24*	17:00	*34*	22:00
5	07:30	*15*	12:30	*25*	17:30	*35*	22:30
6	08:00	*16*	13:00	*26*	18:00	*36*	23:00
7	08:30	*17*	13:30	*27*	18:30	*37*	23:30
8	09:00	*18*	14:00	*28*	19:00		
9	09:30	*19*	14:30	*29*	19:30		
10	10:00	*20*	15:00	*30*	20:00		

Set D contains the departure times of the vehicles, as presented in table 13. The departure times are considered as a hard deadline in this case study. This means that when items are not loaded into the vehicle, the vehicle will leave without these items.

Table 13: Set of departure times of vehicle i

i	Departure time (t)	i	Departure time (t)
1	31	*8*	23
2	9	*9*	7
3	15	*10*	8
4	9	*11*	22
5	17	*12*	9
6	25	*13*	25
7	33		

Set R contains the release times of the vehicles, as presented in table 14. The release times are considered as a hard deadline in this case study because it gives the operators enough time to prepare the packages of the vehicle. Releasing the vehicle too late means there is a chance packages will not arrive on time at the staging lane.

Table 14: Set of release times of vehicle i

i	Release time (t)	i	Release time (t)
1	4	*8*	15
2	23	*9*	23
3	32	*10*	1
4	30	*11*	32
5	32	*12*	36
6	10	*13*	17
7	14		

5.1.2 Input parameters

A distance matrix will be introduced to calculate the marshalling processing time, as presented in table 15. This distance matrix presents the distance between the four pack locations and the different staging lanes in meters. The distance is measured using a measuring wheel, as this provides the most accurate distance.

Table 15: Distance from pack location to staging lane

j	Parcel	Rack	Large	Bypass
1	22,6	52,6	76,6	60,6
2	26,6	56,6	80,6	64,6
3	30,6	60,6	84,6	68,6
4	34,6	64,6	88,6	72,6
5	38,6	68,6	92,6	76,6
6	44,5	74,5	98,5	82,5
7	48,3	78,3	102,3	86,3
8	46,35	76,35	100,35	84,35
9	49,85	79,85	103,85	87,85
10	53,9	83,9	107,9	91,9
11	56,9	86,9	110,9	94,9
12	59,9	89,9	113,9	97,9
13	62,9	92,9	116,9	100,9
14	65,15	95,15	119,15	103,15

The average speed of a forklift has been estimated to be 2,78 m/s, as this is the speed at which a forklift can safely operate (Zuuring, 2019). A safe operating speed is important as several people work with MHEs on the route between the pack locations and the staging lanes.

The number of packages for vehicle *i* that is packed at the pack stations in November 2021 is presented in table 16.

Table 16: Number of packages for vehicle i packed at pack location p

i	Parcel	Rack	Large	Bypass
1	25	18	6	31
2	22	14	8	33
3	21	16	5	28
4	32	16	5	40
5	35	17	12	45
6	36	15	6	48
7	30	19	8	39
8	53	11	2	20
9	12	18	31	30
10	16	2	10	14
11	52	16	7	30
12	6	8	2	10
13	16	9	1	3

To make sure that staging lanes are not getting congested, the volume of vehicles are introduced. The volume of vehicles in this case study are based on the shipments of November 2021. The volume of the vehicle cannot exceed the capacity of the staging lane, as an overcrowded staging lane can increase the loading time due to an increase in search time. As presented in table 17, the majority of the volumes of the vehicles are between eighteen and twenty-five cubic meters. In addition, four carriers have an average volume smaller than ten cubic meters.

Table 17: Volume of shipments for outbound vehicles

i	Volume
1	20,6
2	23,8
3	24,7
4	20,2
5	18,2
6	9,54
7	27,6
8	5,2
9	23,3
10	5,2
11	21,6
12	9,05
13	0,2

To ensure that staging lanes are not overcrowded, a maximum capacity is introduced, as presented in table 18. The capacity is based on the depth and width of the lanes and the permitted stacking height. The permitted stacking height in the outbound area at CEVA Logistics is two meters.

Table 18: Capacity of staging lanes

j	**Capacity**
1	60,8
2	60,8
3	60,8
4	60,8
5	60,8
6	22,8
7	22,8
8	53,2
9	53,2
10	45,6
11	45,6
12	45,6
13	45,6
14	22,8

Finally, the minimal slack time, ST, has been set to 60 minutes (two time frames) to make sure that a small delay will not cause congestion or packages from different vehicles in the same staging lane.

5.2 Experimental settings

To obtain the results from the model, the conceptual model will be programmed in Python using Gurobi Optimizer. Gurobi Optimizer was chosen for this case study because it is one of the most powerful mathematical programming solvers available. When the model has been programmed, the sets and parameters introduced in the previous section will serve as input to the conceptual model and will be ran on an Intel Core i7-4800 2.4 GHz processor. With these input sets and parameters, Gurobi will optimise the conceptual model. Which will result in an optimal staging lane schedule, minimising the distance the marshaller has to travel and, therefore, the time he spends marshalling.

6. Results

This chapter includes the results of the model formulated in chapter 4 and the case study presented in chapter 5. The results are divided into four sections. Firstly, the results of the staging lane schedule will be presented. Secondly, the results of the total marshalling time will be presented. Thirdly, the effect of a change in release time and number of carriers will be discussed. Afterwards, a sensitivity analysis will be conducted. Finally, the results of the model will be discussed.

6.1 Staging lane schedule

In this section, the staging lane assignment problem results are provided. The outgoing shipments are rescheduled based on the marshalling time and the volume of the shipments. The marshalling time is determined based on historical data of November 2021 and the marshalling time formula (1). The volume of the shipments is just like the marshalling time based on historical data of November 2021, as presented in table 17.

The new staging lane schedule is presented in appendix D. The staging lanes schedule shows which vehicle is assigned to which staging lane at a certain moment during the day. For example, vehicle 4, in this case study DGF 1, is assigned to staging lane 1 from 20:00 until 10:00 the next day. In the staging lane schedule, all daily arriving vehicles have been assigned to a certain staging lane minimizing the total marshalling time of all vehicles.

Besides, in the new staging lanes schedule, the number of staging lanes used to consolidate all the packages of a vehicle are less than in the current schedule. In the new schedule, in total, ten staging lanes are used for all the vehicles, wherein the current staging lane schedule, the number of used staging lanes is equal to fifteen. The decrease in the number of staging lanes used is mainly caused by using the dynamic allocation policy, as the dynamic allocation policy minimizes the required space (de Koster et al., 2007). With the use of the dynamic allocation policy, a staging lane can be used for multiple vehicles a day. For example, staging lanes 1, 2 and 7 are used for two different vehicles. This way, in the current staging lane schedule, only the case for the staging lane of Schenker and DGF, as both these carriers had multiple vehicles a day.

In addition, with the use of the dynamic allocation, the number of staging lanes used for all DGF vehicles is decreased from seven to four. The decrease in staging lanes makes it for the expedition employees easier to locate the correct package for a vehicle, as all the packages are located in a single staging lane instead of searching for packages in different staging lanes.

6.2 Marshalling time

In this section, the results of the total marshalling time will be presented. The total marshalling time is based on the current staging lane schedule, which uses a dedicated allocation policy, and the new staging lane schedule, which uses a dynamic allocation policy.

The total distance a marshaller needs to travel to bring all the packages of a certain carrier from the pack location to the desired staging lane is presented in figure 9. The figure shows a comparison between the distance a marshaller travelled under the current staging lane schedule and the new staging lane schedule. The comparison shows that for all carriers, the total distance travelled has decreased from 167,15 km to 151,08 km, which is a decrease of 10,7%. The total distance decreases for all carriers, except for Schenker 1 and 2 and Seacon. The increase in total distance of Schenker 1 and 2 and Seacon can be explained because this staging lane is located closest to the pack locations in the current layout. In the new staging lane schedule, Schenker 1 is assigned to staging lane 8 and Schenker to staging 9, which are both located further from the pack locations as the currently dedicated staging lane of Schenker. For Seacon, the distance has only increased by 619 meters.

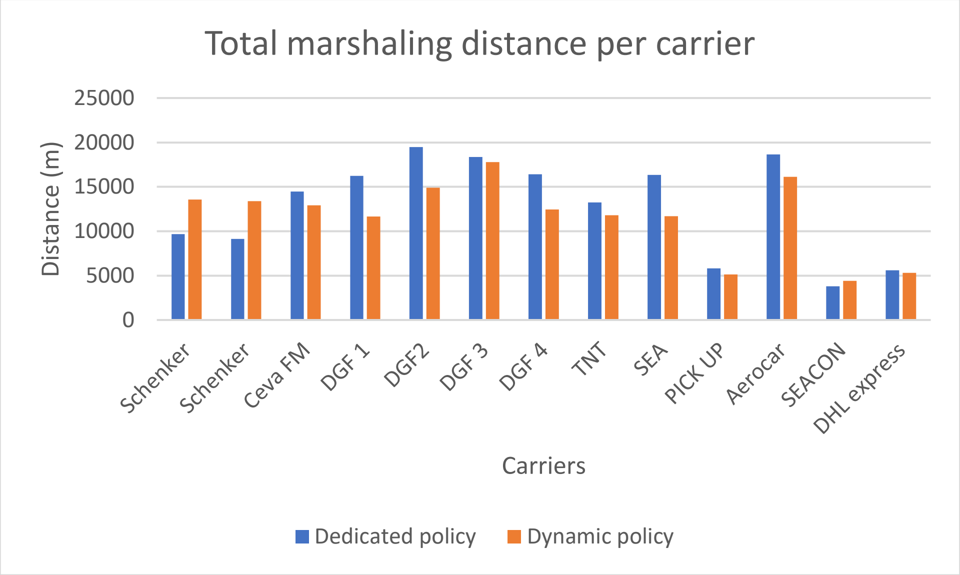

Figure 9: Total marshall distance per carrier

The total marshalling time per carrier is presented in figure 10. From this figure, the same conclusion emerges from the total distance analyse; Schenker 1 and 2 and Seacon have a longer marshalling time than with the dedicated staging lane policy. The increase in total marshalling time may affect arriving in the staging lane on time, as Schenker 1 takes 23 minutes and Schenker 2 takes 26 minutes longer to get all packages from the pack location to the staging lane. For Seacon, it is not very likely to cause problems as it only takes four minutes longer to transport all the packages to the staging lane. However, the total time the marshallers are transporting the packages from the pack location to the staging lanes decreases from 16,72 hours to 15,11 hours. This decrease in total marshalling time results in a decrease in pick-to-ship cycle time, which leads to a reduction in the cost spent on the outbound process. Besides, the decrease ensures that the marshallers can start marshalling the packages earlier, ensuring that the packages from Schenker 1 and 2 still arrive around the same time as with the dedicated staging lane policy.

However, if it turns out that Schenker 1 and 2 still do not arrive on time in the staging lanes. This potential problem could be solved by releasing Schenker 1 and 2 earlier. This would not cause any problems in this case, as Schenker 1 and 2 are both the only vehicles assigned to staging lanes 8 and 9.

Finally, assuming that the productivity at the pack locations remains the same. The decrease in total marshalling time will most likely cause the number of packages at the pack locations to decrease due to the increase in the number of packages marshalled per hour.

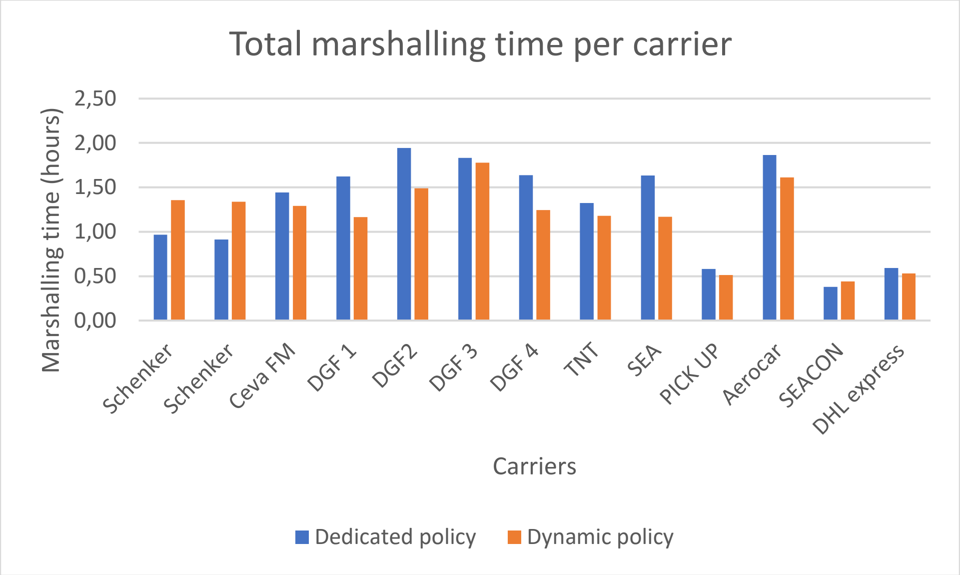

Figure 10: Total marshalling time per carrier

6.3 Release of the vehicle

Due to the decrease in marshalling time and the decrease in vehicle loading time because of the dynamic staging lanes and dynamic staging lane policy, CEVA Logistic could release the vehicles later. Releasing the vehicle later will result in an even further decrease in the total marshalling time, as presented in figure 11. In figure 11 can be observed that when the vehicles are released 30 minutes later, the total marshalling time decreases from 15,11 hours to 14,96 hours, which is a decrease of 1%. The decrease in marshalling time can be explained by the fact that it is possible to assign multiple vehicles to a single staging lane during the day due to the shorter time between the release and departure of the vehicle. Releasing the vehicle 60 minutes later than the current release time only lowers the total marshalling time by 2 minutes hours compared to releasing 30 minutes later. Releasing the vehicles 90 minutes later than the current release time results in a 31-minute decrease, equal to a decrease of 3,4%.

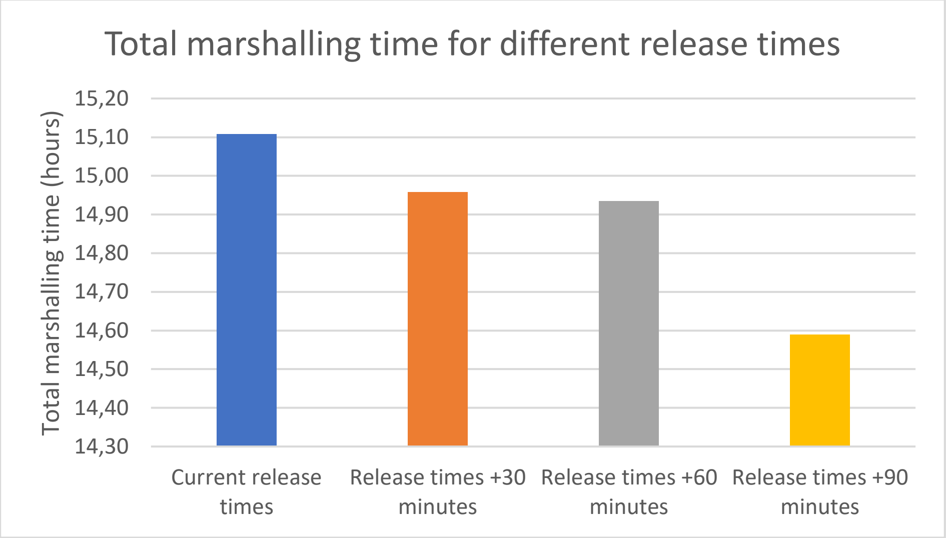

Figure 11: The effect of releasing vehicles later on the total marshalling times

Comparing the decrease in marshalling time to the decrease in time between the release and departure of a vehicle, it is not feasible for CEVA Logistics to release the vehicles later because of the decrease in marshalling time, which is equal to 1,77 hours, compared to the total decreases in time between the release and departure of a vehicle, which is equal to 6,5 hours, is smaller. On the other hand, it is possible to release the vehicle with the largest decrease in total marshalling time (DGF 1; DGF 2 and SEA) 30 minutes later as the staging lane schedule does not change compared to the staging lane schedule with the current release times.

However, as mentioned in section 6.1, the introduction of dynamic staging lanes ensures that vehicles are no longer assigned to multiple staging lanes. Assigning a vehicle to a single staging lane will decrease the loading time of a vehicle because expedition employees spend less time searching for packages in different staging lanes. This decrease in loading time may make it possible for CEVA Logistics to release the vehicles 30 minutes later than is currently the case.

6.4 Sensitivity analysis

In this section, a sensitivity analysis is carried out on three parameters, the number of carriers, the volume of the shipment, and the minimal slack time. The number of carriers has effect on the total marshalling time as an increase in the number of carriers causes changes in the assignment of vehicles and the number of packages transported. Besides, the volume of the shipments has effect on the staging lane schedule as the volume of the vehicle cannot exceed the capacity of the staging lane. Furthermore, the minimal slack time has effect on the staging lane schedule as the time between the assignment of two consecutive vehicles cannot be smaller than the minimal slack time.

6.4.1 Number of arriving vehicles

CEVA Logistics may want to increase the number of items shipped in the future. In order to be able to ship these extra lines, the number of vehicles arriving at the warehouse will increase. The case study introduced in chapter 5 is expanded with one up to five randomly generated new arriving vehicles to see whether the dynamic staging lanes can handle this growth. These vehicles have randomly generated release and departure times, number of packages, and volumes, as presented in appendix E.

In figure 12 can be observed that the dynamic staging lane policy still decreases the total marshalling time when the number of arriving vehicles increases. However, in this case study, when the number of carriers increases to 18, it is impossible to generate a feasible staging lane schedule due to the lack of available staging lanes. A possible solution could be to introduce an additional staging lane. However, due to the limited space for the staging lanes, other staging lanes have to be made smaller to create space for a new one. Another solution could be to reduce the minimal slack time because reducing the minimal slack time leads to tighter assignments. Tighter assignments of vehicles could lead to a reduction of the operational staging lanes. However, reducing the minimal slack time will not guarantee a feasible solution because the release and departure times of the vehicles are fixed in this case study.

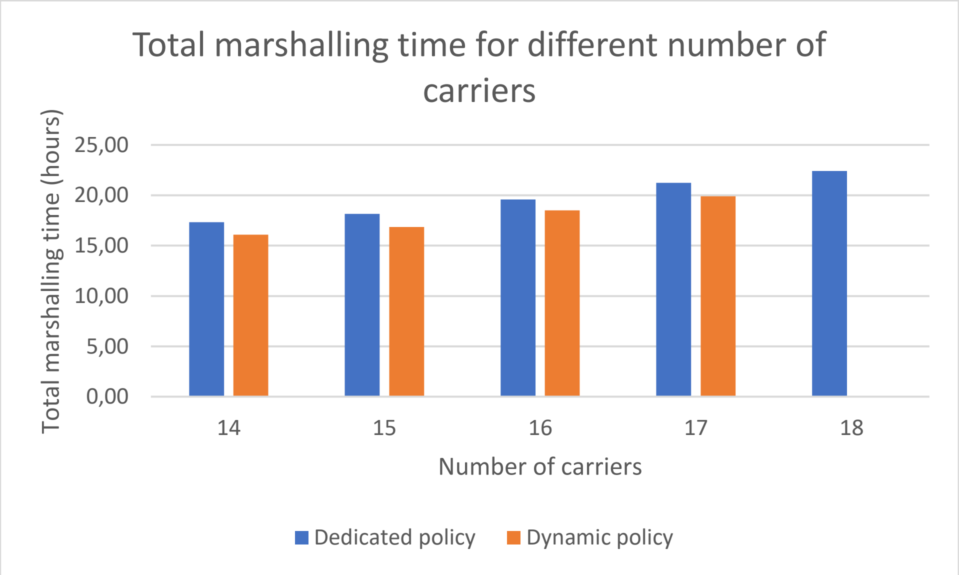

Figure 12: The effect of additional carriers on the total marshalling time

Secondly, the decrease in total marshalling time changes with the change in number of carriers. The reduction of total marshalling time goes up when the additional carrier is assigned to a staging lane far away from the pack locations under the dedicated policy. When the additional carrier is assigned to a staging lane close to the pack locations, the reduction in total marshalling time decreases. For example, when an additional vehicle of Schenker arrives, the decrease in total marshalling time only remains the same if Schenker is placed under the dynamic policy in the nearest staging lane. Otherwise, Schenker's vehicle will be assigned further away from the pack locations, which will result in a higher marshalling time for the Schenker vehicle under the dynamic policy than in the dedicated policy.

6.4.2 Volumes of vehicles

As defined in section 5.1.2, the volumes of the vehicle (v_i) represents the total volume of all the packages intended for vehicle i. The volume of the vehicle has been introduced to ensure the vehicle is assigned to a staging lane with enough capacity and avoid congestion.

In general, a decrease in the volume, assuming that the number of packages stays the same, will lead to no change in the staging lane schedule as the volumes will not exceed the capacity of the staging lanes. However, it could be possible that the volume of a vehicle was too large to fit in a staging lane and will fit when the volumes decrease.

When the volumes increase, assuming that the number of packages stays the same, it is more likely that the staging lane schedule and, therefore, the marshalling time will change due to an exceeding of the capacity of the staging lane. Therefore, a sensitivity analysis is performed on the volumes of the shipments.

Total marshalling distance

The change in total marshalling distance due to the change in the volume of the vehicle is presented in appendix G. The fluctuation in staging lane capacity is analysed to see the effect on the total marshalling distance when CEVA Logistics decides to reduce the staging lane capacity. The change in total marshalling distance is presented in figure 13. It can be observed from figure 13 that a 40 and 50 per cent decrease in volume does not affect the total marshalling distance compared to the different capacities. With a decrease in volume of minus 30 per cent, an increase in marshalling distance can be observed by a capacity of minus 30 per cent. This increase is caused by two vehicles exceeding the capacity of the staging lane and must be moved to another larger staging lane. However, the decrease of ten per cent in volume caused a change in total marshalling distance of minus 0,23 per cent.

Besides, there are several increases in the total marshalling distance. These are again caused by a vehicle exceeding the capacity of the staging lane and being assigned to another larger staging lane. Compared to the increase in volume, these increases are very small: 0,07 and 0,9 per cent.

With an increase in the volume of 40 per cent, a relatively large increase in total marshalling distance can be seen at a capacity of minus 30. This strong increase is caused by the fact that an extra staging lane is required to provide all vehicles with a suitable staging lane. In addition, it can be observed that with an increase in the volume of 50 per cent and a capacity of minus 30 per cent, it is no longer possible to create a staging lane schedule in which the capacity of the staging lane is exceeded, or multiple vehicles are stored in a staging lane at the same time.

Overall, it can be concluded that a smaller capacity has little effect on the total marshalling distance. However, when the capacity of the staging lanes is too small, an increase in volume can lead to an infeasible staging lane schedule because there are too few staging lanes available with sufficient capacity or because the volume of a vehicle is greater than the maximum capacity of the staging lane.

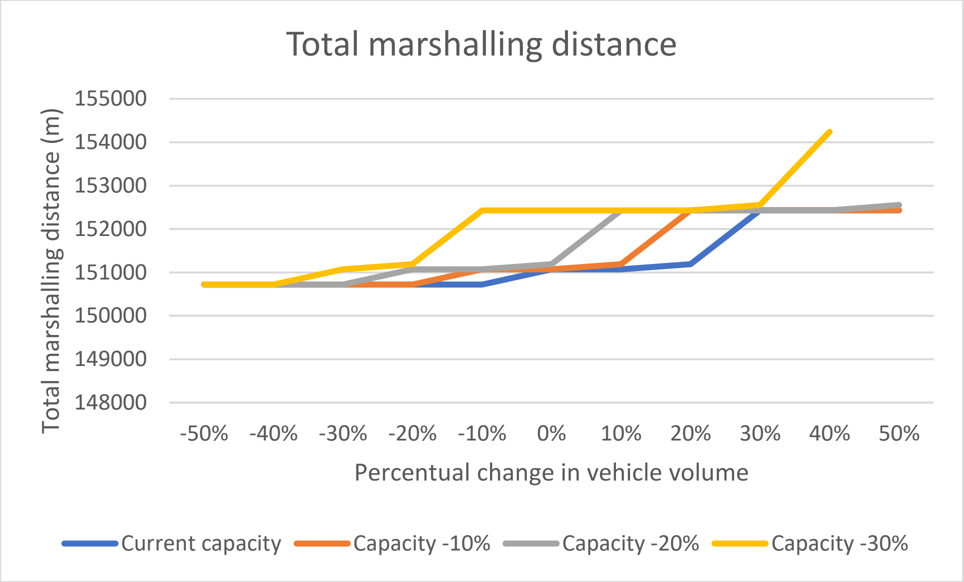

Figure 13: The effect of vehicle volume on the total marshalling distance

Since the change in total marshalling distance is relatively small, the change in marshalling time is also relatively small. The relatively small change in total marshalling time ensures that the volume per hour is almost equal to the change in volume, as presented in figure 14. It can be concluded that a change in volume has little effect on the staging lane schedule in this case study.

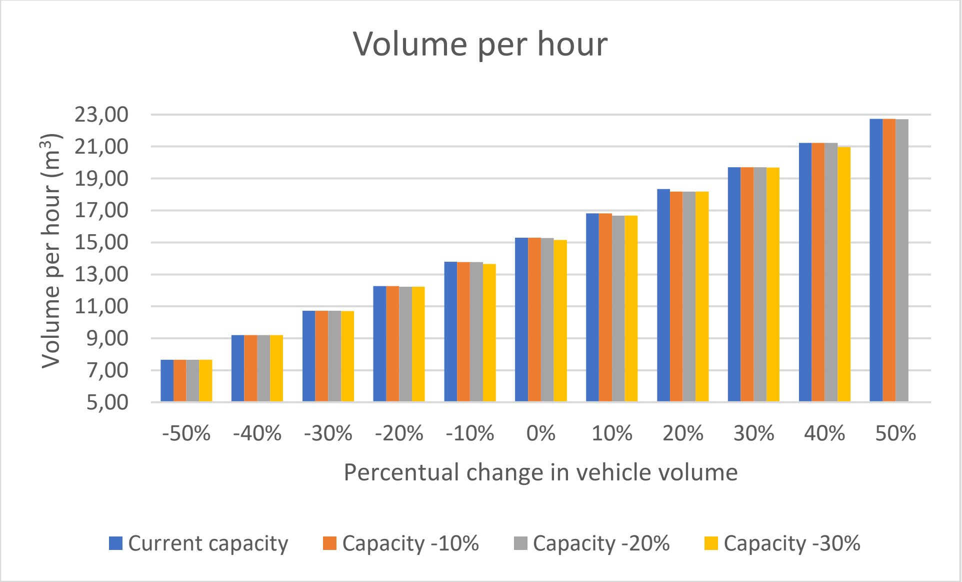

Figure 14: The effect of vehicle volume on the volume per hour marshalled

6.4.3 Minimal slack time

As defined in section 5.1.2, ST represents the minimal slack time between to assignment of vehicles. Minimal slack time is introduced to ensure a small vehicle delay will not cause problems in the staging lane. In general, a smaller slack time results in a tighter schedule because staging lanes become immediately available after the scheduled departure of the vehicles, and possible delays are not taken into account. A sensitivity analysis will be performed on the minimal slack time to see the effect on the total marshalling time.

Total number of staging lanes in use

The number of staging lanes can fluctuate due to the change in minimal slack time because the fit of the schedule can be tighter with a lower minimal slack time. To demonstrate the impact on the number of staging lanes, different minimal slack times are used to schedule the vehicles of the case study. In figure 15 can be observed that with a minimal slack time of zero and 30 minutes, the number of staging lanes is equal to nine. However, as presented in appendix G, the staging lane schedule with a minimal slack time of zero minutes is very tight. In the first staging lane, the vehicles are assigned directly after each other, leaving no room for any delay. For the staging lane schedules with a minimal slack time equal to 60, 90, 120 and 150 minutes, the number of staging lanes is equal to ten. Finally, when the minimal slack time is set to 180 minutes, the number of staging lanes increases to eleven, as presented in appendix G.

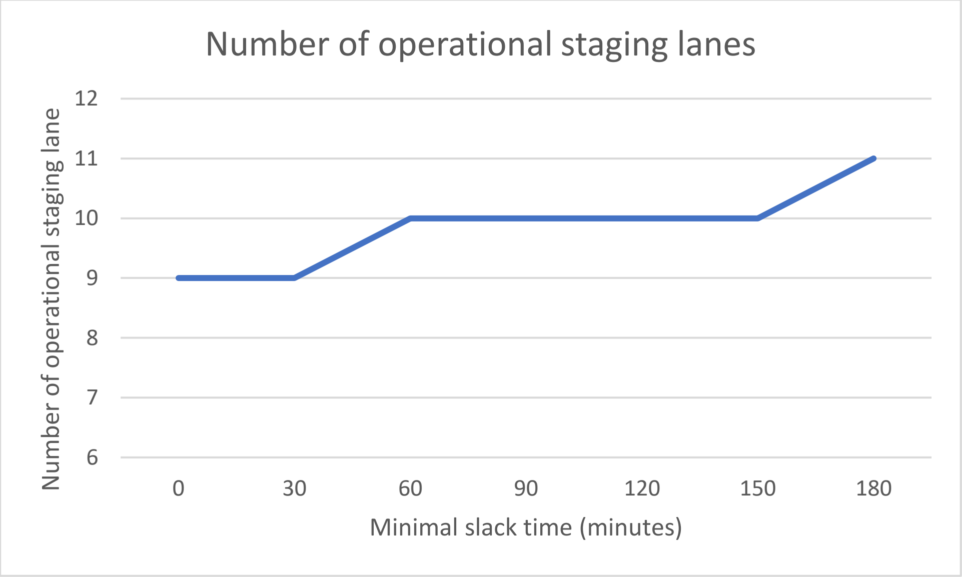

Figure 15: The effect of minimal slack time on the number of operational staging lanes

Total marshalling time

The total marshalling time to bring all the packages to the staging can fluctuate due to the changes in minimal slack time because a change in minimal slack time can affect the assignment of a vehicle to a staging lane. Figure 16 shows the effect of the change in minimal slack time on the total marshalling time. When a minimal slack time of zero or 30 minutes is used, the total marshalling time is 0,18 and 0,15 hours shorter than the total marshalling time with a minimal slack time of 60 minutes. With a minimal slack time of 60, 90, 120 and 150 minutes, the total marshalling time is equal to 15,11 hours. The constant total marshalling times of these minimal slack times can be explained by the fact that when using a minimum slack time of 60 minutes in this case study, the shortest time between two consecutive vehicles equals five, as presented in the staging lane schedule in appendix D. When using a minimum slack time of 180 minutes, the total marshalling time is a lot higher, namely 0,55 hour. This increase is explained by the fact that an additional staging lane has to be used, as presented in figure 15. This additional staging lane is located further away from the pack locations, requiring the marshaller to travel a greater distance.

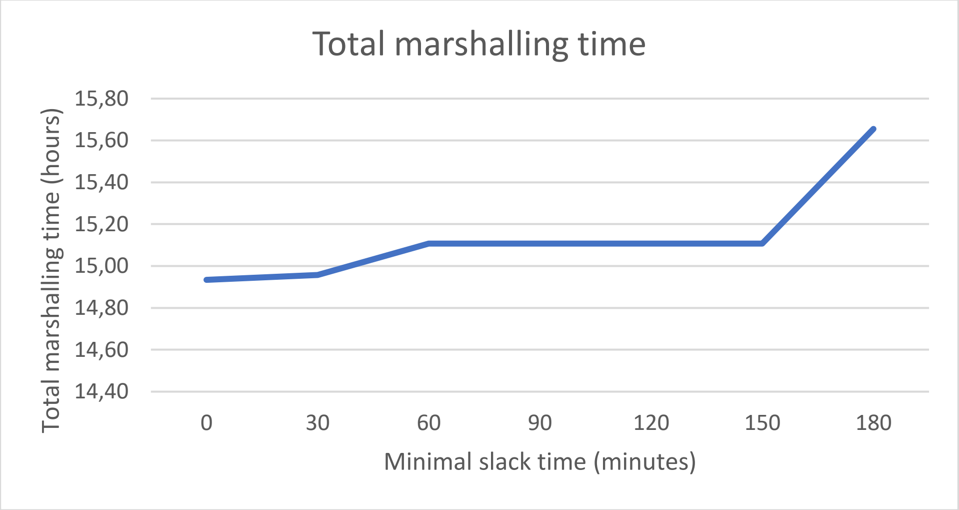

Figure 16: The effect of minimal slack time on the total marshalling time

An increase in marshalling distance due to an increase in minimal slack time will lead to an increase in the total marshalling time. Ultimately, resulting, assuming that the volume is fixed, in a lower volume per hour, as presented in figure 17.

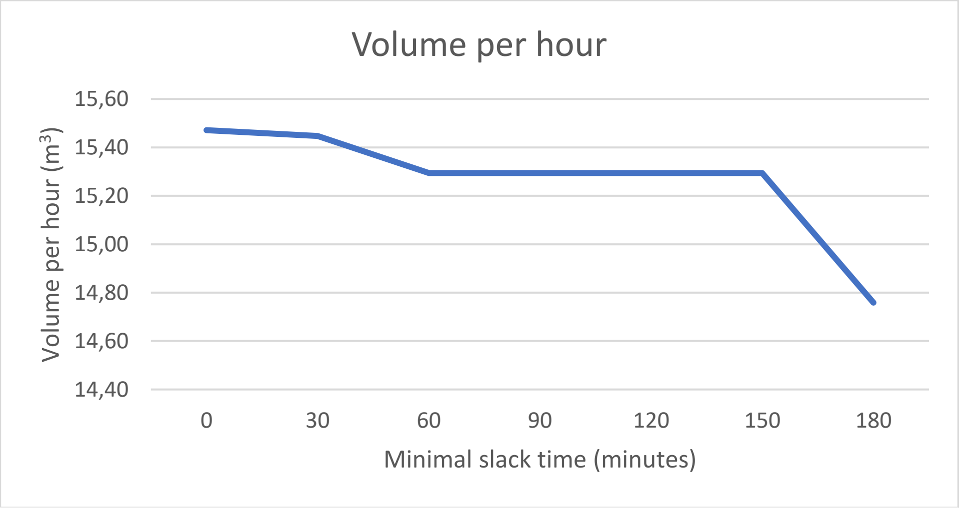

Figure 17: The effect of minimal slack time on the volume per hour

6.5 Discussion

The model is calculated under simplified characteristics. In practice, some characteristics are different; therefore, this section discusses the simplified characteristics and the effect these characteristics have on the actual staging process.

Firstly, the sensitivity analysis of the minimal slack time shows that when the minimal slack time is equal to zero minutes, the total distance the marshaller needs to travel is the shortest. As presented in appendix G, the model assigns two vehicles direct after each other in the first staging lane, leaving no room for any delay. In the model, leaving no room for delay is not a problem due to the assumption that there are no delays. However, in a more realistic environment, the truck will not always arrive and leave exactly on the planned arrival and departure time. The uncertainty in arrival and departure time can lead to problems for trucks that arrive later than the scheduled arrival time and therefore depart later than the planned departure time plus the minimal slack time. A possible solution could be to switch the vehicle assigned to the same staging lane as the delayed truck to an issue lane or another available staging lane. Switching to another staging lane prevents packages of different vehicles to be mixed in one staging lane. The switch to another staging lane has a negative effect on the total marshalling time because it deviates from the optimal staging lane schedule. The worst-case scenario for the staging lane schedule with a minimal slack time of zero minutes is presented in table 19, which is transporting the packages of a vehicle to staging lane 14 instead of its original assigned staging lane. The total marshalling time is still lower compared to the total marshalling time under the dedicated staging lane policy because the largest addition time of 54 minutes is smaller than the initial decrease of marshalling time of 1,61 hours.

Table 19: Addition time to marshall the packages of a vehicle to staging lane 14

Vehicle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Additional time with a minimal slack time 0 minutes (minutes)	18	15	26	48	27	54	45	36	29	20	21	11	11
Additional time with a minimal slack time 30 minutes (minutes)	18	15	26	48	27	49	41	44	29	20	21	11	11

However, comparing the total marshalling time of the staging lane schedule with a minimum slack time of 60 minutes, the additional time required for switching the packages of a vehicle that has to be reassigned to staging lane 14 due to a delay is greater than the decrease in total marshalling time, which is equal to 11 minutes, as presented in figure 18. Therefore, it is important to include a minimal slack time of 60 minutes in the dynamic staging lane policy to make the staging lane schedule robust for delays.

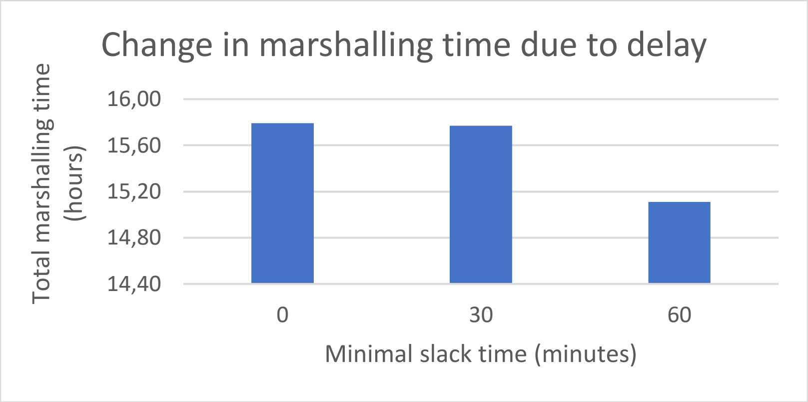

Figure 18: Change in marshalling time due to a delay of a vehicle

Secondly, the demand is now taken from historical data. In a more realistic environment, the staging lane schedule is based on a forecast of the volume and number of packages of a vehicle. The quality of the forecast affects the quality of the staging lane schedule as the staging lanes schedule is based on these parameters. For example, when the volume of a vehicle is forecasted too low. There is a chance that the vehicle will be assigned to a staging lane that is too small for the actual volume of the vehicle. The incorrect forecast could lead to congestion in the staging lane, which increases the probability of packages not being located, resulting in packages being dropped out of the shipment (Van Niekerk, 2017). Dropped packages contribute to excessive shipment loading times, as loading staff has to spend much time locating the packages, reducing the loading efficiency (Van Niekerk, 2017). Alternatively, the vehicle with a too low predicted volume is moved to a larger staging lane, providing additional marshalling time, as presented in figure 19. To reduce the chance of congestion due to a forecast error, capacity slack should be taken into account (Guignard et al., 2012). Capacity slack is a capacity buffer to ensure that an increase in the volume can be absorbed. For example, when a 15% capacity slack is used in this study case, the smallest forecast error which has effect on the staging lane schedule is equal to 25%.

A too high forecast of the volume will probably lead to fewer problems in terms of congestion. However, when the forecast of the volume is too high, the staging lane schedule could be suboptimal because, for example, an incorrect forecasted vehicle is assigned to a large staging lane which is, in the case study, located close to the packing stations. When the actual volume of the vehicle is lower, a switch of the incorrect forecasted vehicle with another vehicle could lead to a lower marshalling time, as presented in figure 19.

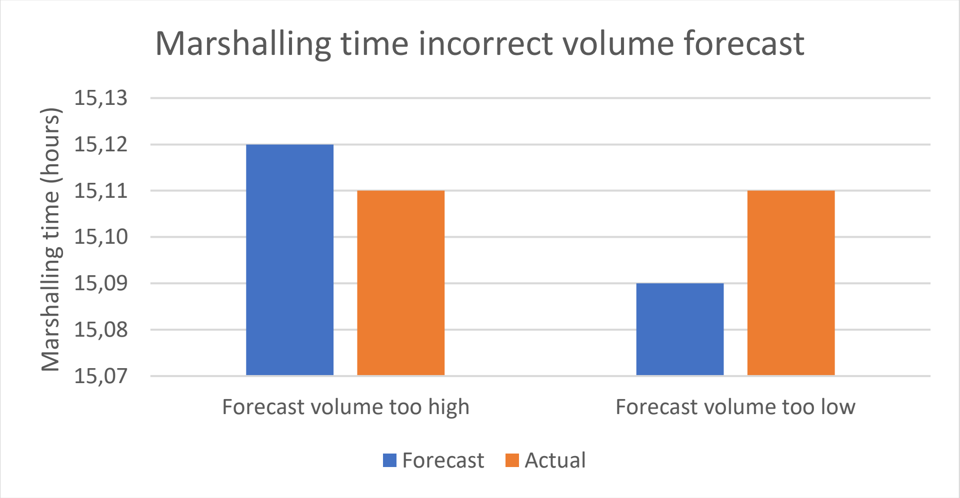

Figure 19: The effect of an incorrect forecast on the marshalling time

Besides, when the number of packages is forecasted too low, the chance that a vehicle is assigned to a staging lane further from the pack locations is high. When the actual number of packages turns out to be higher, the increase in marshalling time is significant since the vehicle is assigned to a staging lane far from the pack locations, as presented in figure 20. The increase in marshalling time could lead to another vehicle having to be switched to a different staging lane because the vehicle has been assigned to the staging lane for longer because of the wrong forecast. The same holds for a forecast with a too high number of packages. The wrong forecast could lead to a suboptimal staging lane schedule. For example, when a high number of packages is forecasted for a vehicle, there is a high probability that the vehicle will be assigned to staging lanes close to the pack locations. However, when in practice, the vehicle has a lower number of packages, switching between a vehicle with a higher number of packages could improve the staging lane schedule.

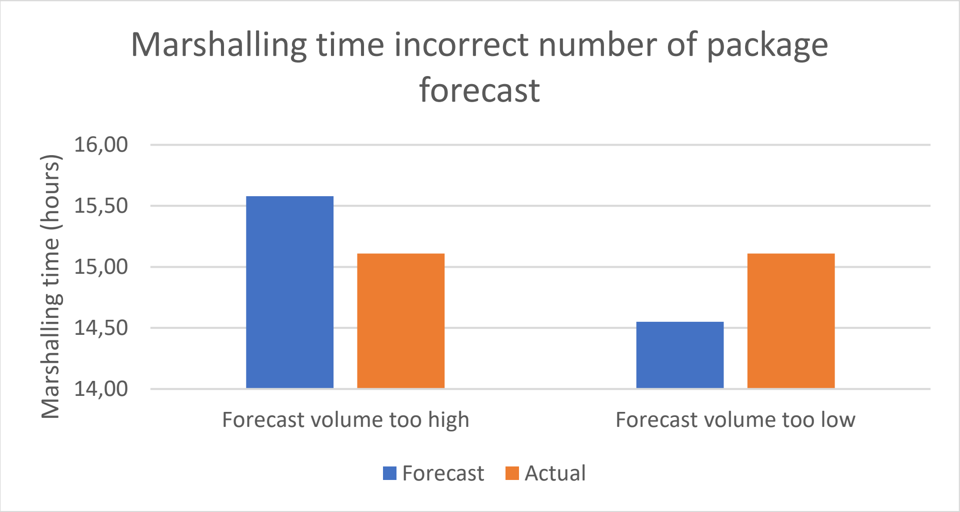

Figure 20: The effect of an incorrect forecast on the marshalling time

7. Conclusion

The last chapter of this thesis includes the answer to the main research question and sub-questions stated in section 1.3 and gives some company recommendations. Furthermore, the academic and practical relevance will be highlighted. Finally, the limitations and recommendations for future research will be discussed.

7.1 Answer to the research questions

1. *What models for staging lane assignment problems can be found in existing literature?*

The existing literature on the staging lane assignment problem focuses on optimizing cross-dock warehouses by assigning inbound trucks and outbound trucks with the objective to minimise the distance a package needs to be transported within the warehouse. However, these models were not suitable for the problem at CEVA Logistic because CEVA Logistic does not cross-dock products in Eindhoven. Therefore, two topics within the scheduling research field have been reviewed to find a scheduling problem that comes close to the staging lane assignment problem. These two topics are the berth assignment problem and the airport gate assignment problem. As the staging lane assignment problem at CEVA Logistics is relatively small, and the release and departure times are fixed, an exact solution method is used to solve the problem. The constraints introduced in the models of Hansen & Oğuz (2003) and Yu et al. (2016) serve as a basis for the staging lane assignment problem at CEVA Logistics.

2. *How can the layout of the current staging area be improved?*

Improving the layout of the staging area can be done by switching from a dedicated staging lane allocation policy to dynamic staging lanes allocation policy as the dedicated staging lanes allocation policy causes carriers to be tied to a fixed capacity staging lane which causes staging lanes to become congested. In addition, it ensures that all packages of a shipment are placed together in a single staging lane. Consolidating all packages in one staging lane makes it easier for the employees of expedition to prepare a shipment. Finally, it ensures that the storage space is minimized. Besides, an issue lane will be created to ensure that packages remaining in the staging lane will be removed to the issue lane because the remaining packages can cause the staging lane to become congested and will result in an increase in time for preparing a shipment. Finally, the capacity of the staging lanes will be determined based on historical data of the maximum volume of the shipments as the volume of the staging lanes should at least have the capacity of the maximum volumes of the shipment.

3. *What will be the optimal staging lanes schedule for the outgoing shipments of Sandvik?*

A model has been introduced to optimal schedule the shipments to the staging lanes. The goal of the model is to minimise the time a marshaller needs to spend on transporting a shipment to the staging area by assigning a shipment to a certain staging lane. In addition to the objective function, several constraints have been added to meet the requirements of CEVA Logistic, such as a constraint on the capacity of the staging lanes, the minimal slack time, transportation between different staging lanes and the merging of packages from different carriers. A case study has been conducted to see whether the staging lane schedule model improves the staging process. The input data for the case study are the daily shipments of the month of November. The results present that the total distance travelled by the marshaller decreases by 16,07 km, which results in a decrease of 1,61 hours (10,7%) spent on transporting packages from the pack location to the staging lane. With the decrease in total marshalling time, CEVA Logistics could decide to release the vehicle with the largest decrease in total marshalling time 30 minutes later.

The sensitivity analysis on the number of carriers shows that the dynamic staging policy outperforms the dedicated policy when the number of carriers goes up. The sensitivity analysis on the volume of the vehicles shows that the capacity of the staging lanes can be reduced without having much effect on the total distance travelled and the volume marshaller per hour. On the other side, lowering the capacity of the staging lanes increase the change of an infeasible staging lanes schedule as there are too few staging lanes with enough capacity to handle the vehicles. Besides, the capacity of the staging lanes should not be lower than the largest volume of a vehicle because this causes the staging lane schedule to become infeasible. Furthermore, the sensitivity analysis of the minimal slack time shows that reducing the minimal slack time to zero would decrease the marshalling time even further. However, reducing the minimal slack time to zero makes the staging lane schedule vulnerable to delay. Therefore, CEVA Logistics should keep a minimal slack time of 60 minutes to make the staging lane schedule robust for any delays. Finally, the quality of the forecast for both the volume and number of packages must be high as both variables influence the marshalling time.

Based on the answer to the sub-question, the main research question can be answered:

How can the staging process be made more efficient by redesigning the staging lanes and optimising the staging lane scheduling at the warehouse of CEVA Logistics?

Based on the answers to the sub-questions, the conclusion can be drawn that the staging process at CEVA Logistics can be more efficient by switching from a dedicated allocation policy to a dynamic allocation policy in which the outgoing vehicles are assigned based on the minimal time a marshaller spends on transporting the packages from the pack locations to the staging lanes because this reduces the total time spent on the staging process. Besides, the dynamic staging lane allocation policy ensures that a staging lane can no longer become congested due to the capacity constraint and the introduction of the issue lane. Introducing the capacity constraint and the issue lane will result in a reduction of missing packages and a decrease in time spent on preparing a shipment to be loaded. Secondly, CEVA logistics should keep a minimal slack time of 60 minutes between the assignment of two vehicles to the same staging lane to make the staging lane schedule robust for small delays. Finally, to properly assign the outgoing vehicles, it is important that the number of packages per carrier are correctly forecasted as the number of packages influences the assignment of the vehicle to the staging lane and, therefore, the pick-to-ship cycle time.

To successfully implement the suggested improvements, the following recommendations are formulated:

- Change the dedicated staging lanes physically and systematically into dynamic staging lanes.
- Implement the dynamic staging lane allocation policy in the WMS.
- Make it possible in the WMS to scan packages to the issue lane.
- Invest in the quality of the forecast of the shipments.
- Perform a periodic review of the shipped volumes to see whether the staging lane capacity is still sufficient.
- Perform a periodic review on the number of shipments to see whether the number of staging lanes is still sufficient.

7.2 Academic and practical relevance

As mentioned in the literature review, little research is conducted on staging lane assignment problems in a warehouse. Looking at the scientific literature, two topics within the scheduling research field solve a scheduling problem that comes close to the staging lane assignment problem: the berth assignment problem and the airport gate assignment problem. MIP models within these two research topics form the basis of the staging lane assignment model presented in this thesis. The model minimizes the total time spent transporting packages from the pack location to the staging lanes. Constraints have been added to the model concerning the capacity of the staging lanes, the minimal slack time, transportation between different staging lanes and the merging of packages from different carriers. Resulting in a minimisation of the time spent on the staging process and a minimisation of space used in the staging area due to a minimisation of the operational number of staging lanes.

This master thesis also has a practical relevance for CEVA Logistics as the dynamic staging lanes and the proposed staging lane assignment model can be used in daily operations. Using the dynamic staging lanes and the proposed staging lane assignment model results in a decrease in the pick-to-ship cycle time within the warehouse due to a decrease in time spent on the staging process. Besides, the number of missing packages will decrease as the packages are consolidated in a single lane instead of multiple lanes.

7.3 Limitations and recommendations for future research

This section presents the limitations of the research and recommendations for future research.

- The case study is based on historical data from November 2021. Therefore, the volume and number of packages are certain and will not change anymore. However, in practice, the staging lane schedule will be created based on forecasts of the volume and number of packages. Future research has to show how the quality of the forecast will influence the quality of the staging lane schedule.
- In the case study, it is assumed that there are no zero-picks. In practice, it will happen that items are not on stock. When a picker has a zero-pick, the item will automatically be removed from the manifest by the WMS. Removing items from the manifest affects the volume and number of packages in a shipment. Therefore, future research should take zero-pick into consideration.
- In this research, it is assumed that a marshaller always transports a single package at a time from the pack location to the staging area. In practice, this is also the case when the marshaller needs to transport a large package. However, with smaller packages, it often happens that several packages are brought to the staging area in one trip. In future research, the sequence of the packages at the pack locations and the volume of the individual packages must be considered to determine the total marshalling time more accurately.
- In the model is assumed that the forklift travels at an average speed of 2,78 m/s. However, in practice, the operating speed of the forklift depends on a lot of variables, such as the waiting time on other MHEs, the time it takes to pick up a package at a pack location and the time it takes to drop off a package at the staging lanes. The high number of variables in the work speed of the forklift makes it impossible to include them into the model. Therefore, to determine the work speed of the forklift more accurate, the variables that have effect on the marshalling work speed need to be added to the model in future research.

- In the discussion, capacity slack has been introduced as a buffer against forecast errors. However, in the case study, the introduction of the capacity slack has little as the staging lanes are based on the maximum volume of a vehicle. When a company has less space for the staging lanes or vehicles have higher volumes, capacity slack ensures a small forecast error will not cause problems in the staging lane schedule. Therefore, in future research, capacity slack should be considered.
- In this research, only the daily arriving vehicles have been taken into account. However, CEVA Logistics has also one other carrier, HOLD. The vehicle of HOLD only arrives at CEVA Logistics when there is enough volume for a shipment. The vehicle of HOLD only arrived 4 times in November, which was too little to be considered in the case study. Nevertheless, the number of times the vehicle of HOLD arrives can change in the future. Therefore, in future research, the non-daily arriving trucks should be considered in the schedule.
- Finally, in the model, fixed pick-to-ship cycle times are used to schedule the vehicles to the staging lanes due to the high number of variables that has effect on the total processing times. For example, the number and level of training of resources, pick routing, and number and size of the items are some of the factors that have effect on the pick process time, which is one part of the pick-to-ship cycle time (Zwick, 2006; Hsieh & Tsai, 2006). The high number of variables in the pick-to-ship cycle time makes it impossible to include them into the model. Therefore, to create a more accurate staging lane schedule, the variables that have effect on the pick, pack and loading processing time need to be added to the model in future research.

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Appendix A

Figure 21: Congestion in a staging lane

Figure 22: Congestion in a staging lane

Appendix B

Boxplot Shelving

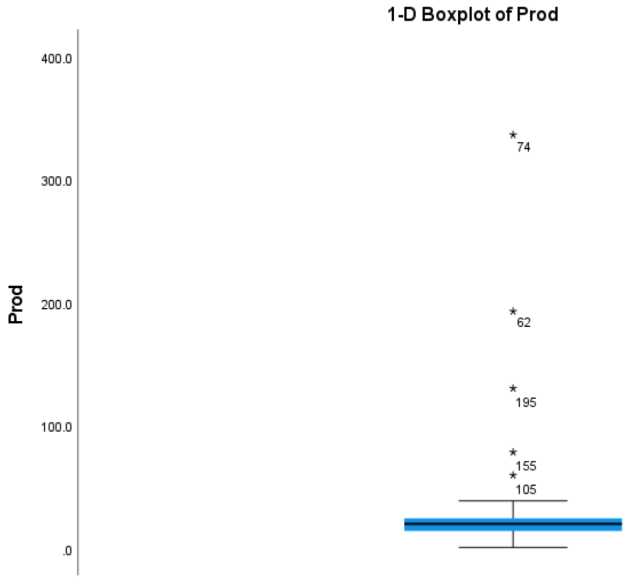


Figure 23: Boxplot productivity shelving

Boxplot HOPT

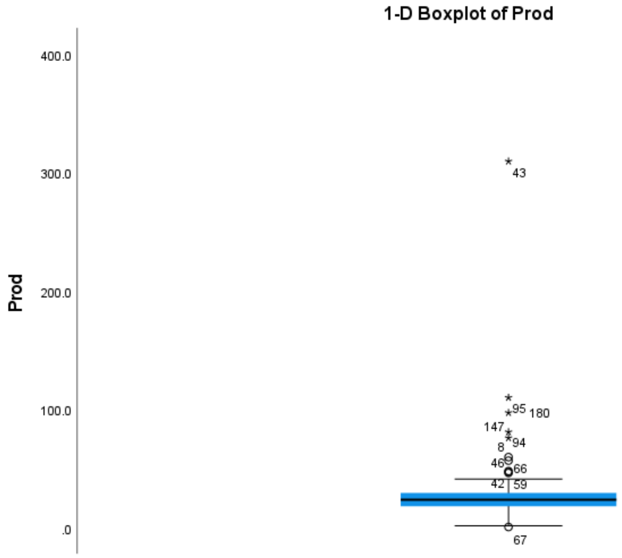


Figure 24: Boxplot productivity HOPT

Boxplot Reach truck

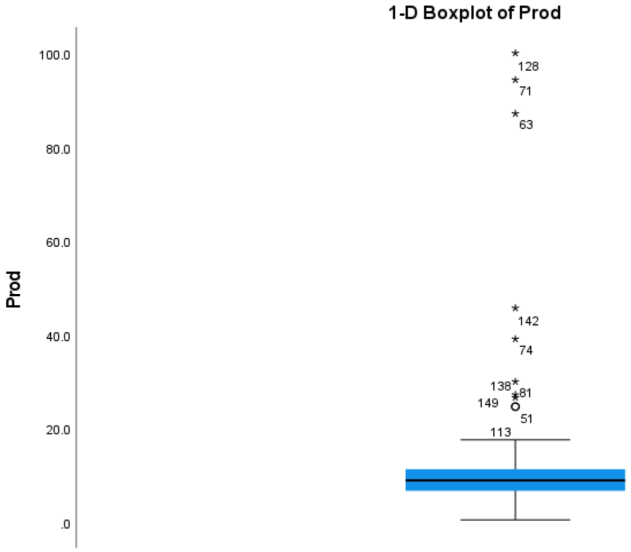


Figure 25: Boxplot productivity reach truck

Appendix C

Boxplot Parcel

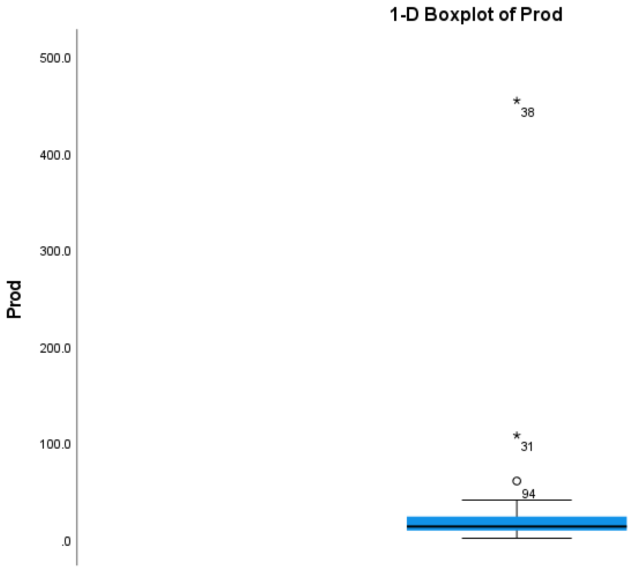


Figure 26: Boxplot productivity parcel

Boxplot Rack

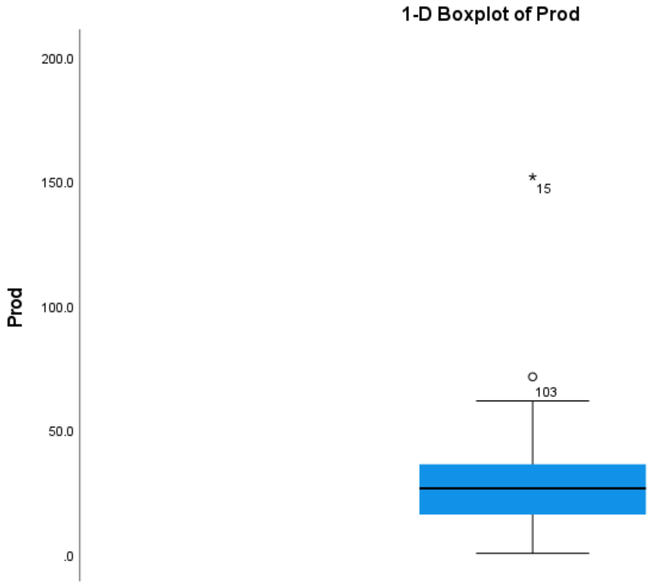


Figure 27: Boxplot productivity rack

Boxplot Large

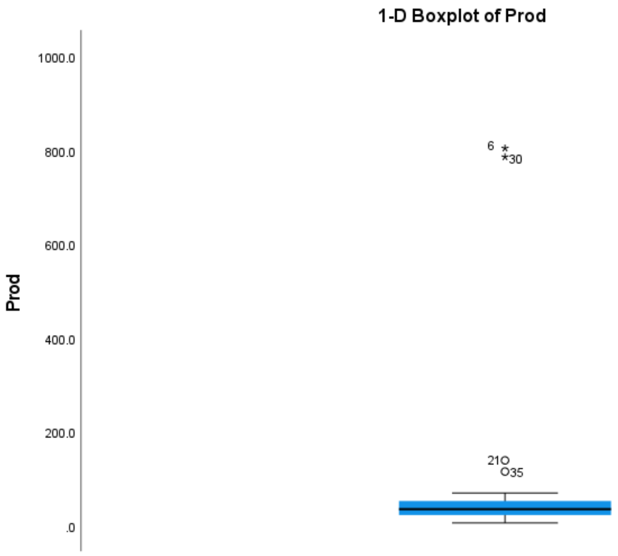


Figure 28: Boxplot productivity large

Boxplot Bypass

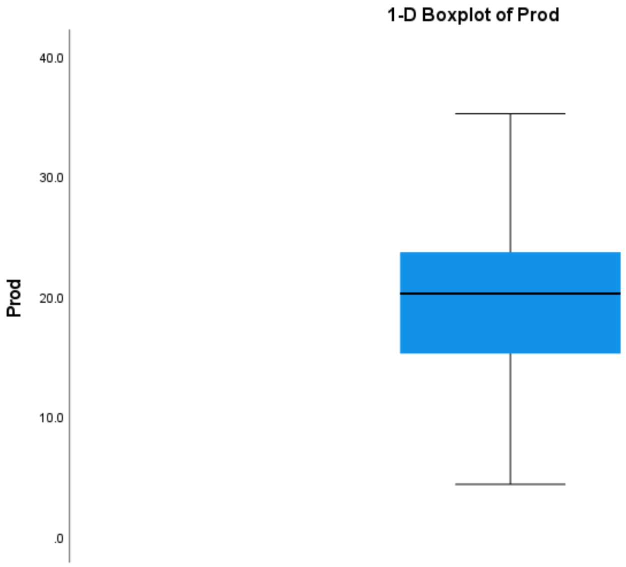
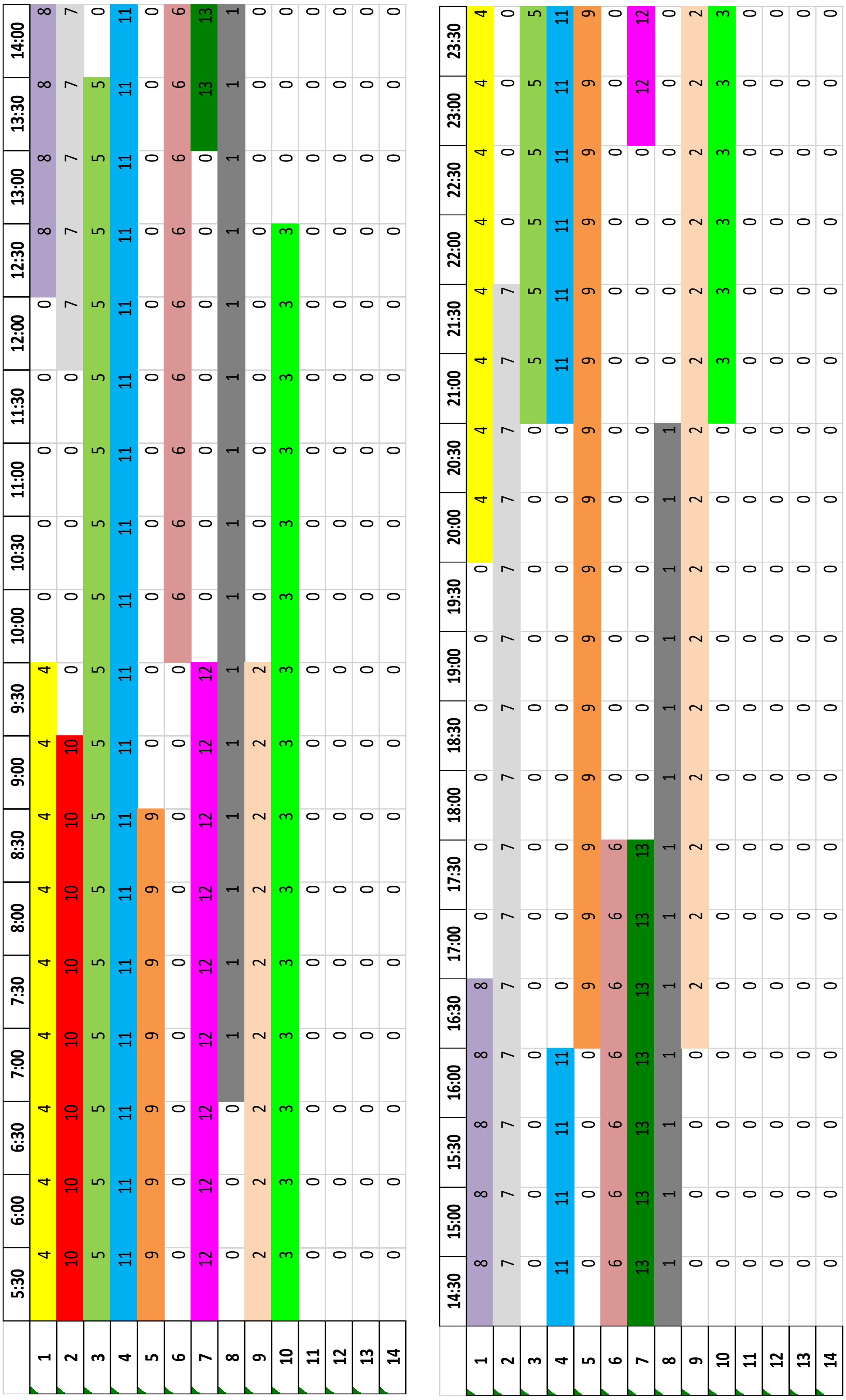


Figure 29: Boxplot productivity bypass

Appendix D



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2	10	10	10	10	10	10	10	10	0	0	0	0	0	7	7	7	7	7
3	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	0
4	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
5	9	9	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0
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12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:30	23:00	23:30
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2	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	5	5
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11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 30: Staging lane schedule of the case study

Appendix E

Table 20: Data of the additional carriers

Vehicle (i)	**Carrier**	**Truck name**	**Arrival time**	**Departure time**	**Volume**	**Pack parcel**	**Pack rack**	**Pack large**	**Bypass**
14	Schenker	14 - Schenker	34	28	13,4	24	8	7	12
15	CEVA FM	15 - CEVA FM	6	33	35	23	4	2	8
16	DGF 5	16 - DGF 5	29	16	36	32	20	9	22
17	SEA	17 - SEA	16	26	27	13	16	36	29
18	TNT 2	18 - TNT 2	14	27	4,2	50	9	1	16

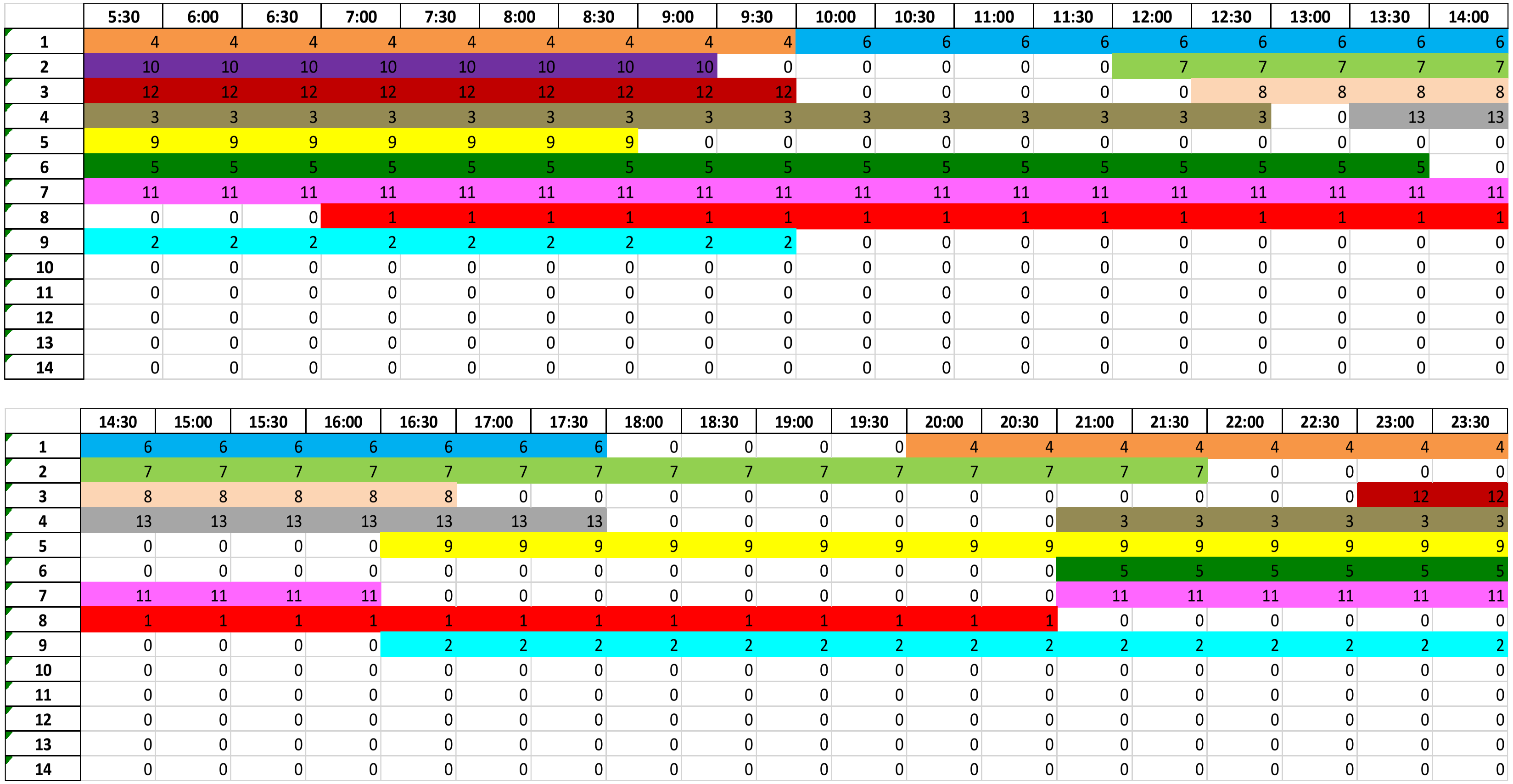
Appendix F

In table 20, the volumes in cubic meters are presented for the sensitivity analysis of the vehicle volume parameter. The different carriers are presented in the rows, and the different volumes compared to the case study are presented in the columns.

Table 21: Volume of vehicles for the sensitivity analysis

Carrier	**-50%**	**-40%**	**-30%**	**-20%**	**-10%**	**0%**	**10%**	**20%**	**30%**	**40%**	**50%**
Schenker	12,05	14,46	16,87	19,28	21,69	24,1	26,51	28,92	31,33	33,74	36,15
Schenker	11,9	14,28	16,66	19,04	21,42	23,8	26,18	28,56	30,94	33,32	35,7
Ceva FM	12,35	14,82	17,29	19,76	22,23	24,7	27,17	29,64	32,11	34,58	37,05
DGF 1	12	14,4	16,8	19,2	21,6	24	26,4	28,8	31,2	33,6	36
DGF2	9,1	10,92	12,74	14,56	16,38	18,2	20,02	21,84	23,66	25,48	27,3
DGF 3	10,05	12,06	14,07	16,08	18,09	20,1	22,11	24,12	26,13	28,14	30,15
DGF 4	14,95	17,94	20,93	23,92	26,91	29,9	32,89	35,88	38,87	41,86	44,85
TNT	2,6	3,12	3,64	4,16	4,68	5,2	5,72	6,24	6,76	7,28	7,8
SEA	12,65	15,18	17,71	20,24	22,77	25,3	27,83	30,36	32,89	35,42	37,95
PICK UP	2,45	2,94	3,43	3,92	4,41	4,9	5,39	5,88	6,37	6,86	7,35
Aerocar	10,8	12,96	15,12	17,28	19,44	21,6	23,76	25,92	28,08	30,24	32,4
SEACON	4,525	5,43	6,335	7,24	8,145	9,05	9,955	10,86	11,765	12,67	13,575
DHL express	0,1	0,12	0,14	0,16	0,18	0,2	0,22	0,24	0,26	0,28	0,3

Appendix G



	5:30	6:00	6:30	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00
1	4	4	4	4	4	4	4	4	4	6	6	6	6	6	6	6	6	6
2	10	10	10	10	10	10	10	10	0	0	0	0	0	7	7	7	7	7
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9	2	2	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0
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12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	21:00	21:30	22:00	22:30	23:00	23:30
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6	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	5	5
7	11	11	11	11	0	0	0	0	0	0	0	0	0	11	11	11	11	11	11
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11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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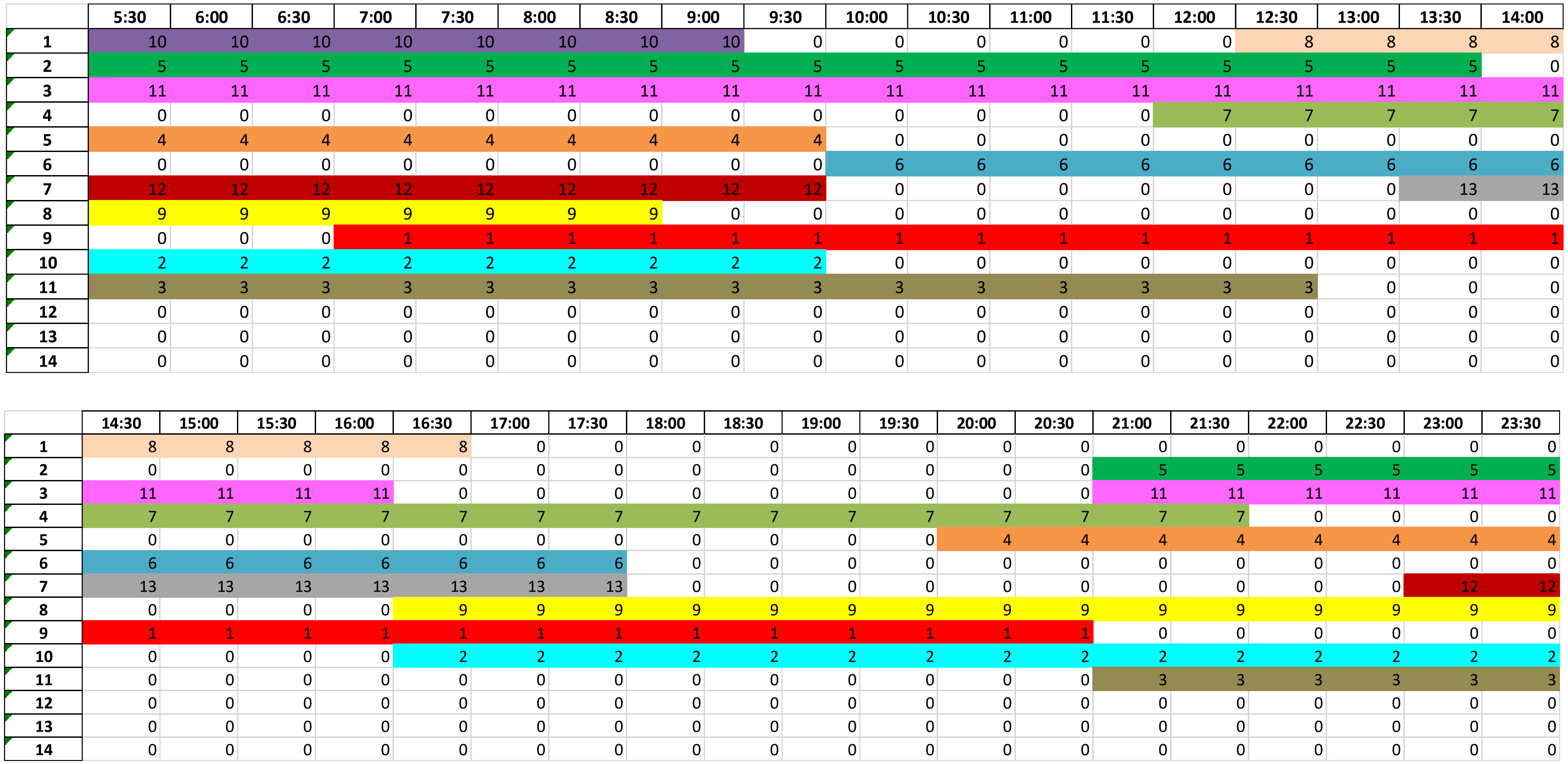
Figure 31: Staging lanes schedule with minimal slack time zero



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6	0	0	0	0	0	0	0	0	0	6	6	6	6	6	6	6	6	6
7	12	12	12	12	12	12	12	12	12	0	0	0	0	0	0	0	13	13
8	9	9	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
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3	11	11	11	11	0	0	0	0	0	0	0	0	0	11	11	11	11	11	11
4	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4
6	6	6	6	6	6	6	6	0	0	0	0	0	0	0	0	0	0	0	0
7	13	13	13	13	13	13	13	0	0	0	0	0	0	0	0	0	0	12	12
8	0	0	0	0	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
9	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
10	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
11	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 32: Staging lanes schedule with minimal slack time six