The use of a marshalling area in the warehouses of Albert Heijn

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Management summary

Albert Heijn (AH), with a total market share of 35.4 per cent in 2016, is the largest supermarket chain in the Netherlands. AH possesses 995 stores in the Netherlands and this number is still growing.

Currently the warehouses make use of a predetermined number of staging lanes for the inbound, outbound and transito flows. A staging lane has a fixed capacity and is assigned to only one of these flows during a certain timeframe. A staging lane is assigned to one trip at a time and only load carriers of that trip may be dropped at assigned staging lane, otherwise *dubbelloop* occurs. This means that the order picking for a given trip can only happen when load carriers can be dropped immediately on the assigned staging lane after finishing the order picking.

The stores are the point of focus for AH. The warehouses have to adapt their processes to satisfy the needs of the stores. In general every store wants to be supplied around the same timeframes. The number of load carriers delivered during the year and week are highly depending on customer demand. The combination of the needs of the stores, demand of the customers and the use of staging lanes results in a fluctuating production during the year, week and day. This will lead us to our problem statement:

"The current flexibility and planning of the production is limited to the capacity and the use of the staging lanes, which makes the production schedule fluctuating and costly. There is a need for a framework that shows the effects of decoupling the production process and the dropping of the load carriers at the staging lanes using a marshalling area and determines the required size of this area."

To get a clear picture of the current situation, we reviewed the whole process from order to delivery by talking to employees, doing observations and perform data analyses. During this review, we especially focussed on the process between the order picking process and the loading of the trucks. Next, we searched for relevant literature that could be useful for our research. Using the information we gained from our review, we created a framework that can be used to determine the required size of the marshalling area giving a production distribution during the week and day. To show the usability of the created framework and the effects of a marshalling area on the production process, we created and executed various scenarios for Distribution Center Zwolle (DCO). From these scenarios at DCO we can conclude the following:

- Implementing a marshalling area at DCO with the lowest required size in the maximum week (1,770) makes sure that the produced load carriers in the maximum week can be

handled by the marshalling area and it gives the possibility to create a more desirable production process in the other weeks of the year.
- Picking of initial promotions load carriers in the beginning of the week leads to a more evenly distributed production planning, but results in a higher required size of the marshalling area.
- A marshalling area can lead to a decrease of the total costs of order pickers in the production process. However, a more evenly distributed production planning results in an increase in the total order pickings costs compared to a situation where more order pickers are allowed to perform order picking at the same time, keeping all other settings the same.
- A marshalling area can lead to a decrease of the standard deviation of the number of order pickers in the production process. A more evenly distributed production planning results in a decrease in the standard deviation of the number of order pickers in the order picking process compared to a situation where more order pickers are allowed to perform order picking at the same time, keeping all other settings the same.
- A one minute decrease in average order pick time (55 minutes and 49 seconds for picking 5 load carriers at the same time) could already lead to a decrease in costs of two per cent compared to a scenario where all other settings are kept the same.

The implementation of a marshalling area could also lead to the following additional benefits.

Potential additional benefits for DCs	Potential additional benefits for stores
Increase in productivity of order pickers	More stores delivered at their desired delivery time
A more efficient use of space	Initial promotions stored at the DCs
Better use of capacity of automated systems	Order of loading can be determined by the store
A safer workplace	
Ready for future growth	
Less impact in case of delays	
Order of loading can be determined by the truck driver	

Table 0.1 Potential additional benefits when implementing a marshalling area

We recommend AH to decouple the production process and the dropping of the load carriers. A marshalling area would be a good solution to the current existing problems regarding the use of the staging lanes and would result in a more flexible production process. We recommend AH to invest in a marshalling area that has the minimum size required to be able to handle the number of produced load carriers during the maximum week (1,770 square meters, based on the created scenarios). This would lead to a size that is large enough to be able to create a more desired production planning during other production weeks with less load carriers to produce.

There are some implementation topics that AH should consider before implementing a marshalling area. A marshalling area will require an investment, the size of this investment depends on the size, type (manual or (parly) automated and the used systems) and layout of the marshalling area. We recommend AH to involve other departments that are influenced by a marshalling area and the employees in the DCs, since implementing a marshalling are will have a big influence on the current way of working.

Lastly, we identify several topics that would be interesting for further research. These include: the broadening of the scope used in this research by including the transit flows and executing the created framework for the other distribution centers; the effects on efficiency if the number of order pickers in the process at the same time is decreased; the effects of using different average order pick times for different order pick areas instead of one average order pick time; the ratio between costs and size of the marshalling area and the determining of the type and layout of the marshalling area.

Acknowledgements

Whit this report, my time at the University of Twente has ended. When I look back on my time in Enschede, I can say that I really enjoyed studying there. I have learned a lot, not only on an academic but also on a personal level. I really enjoyed my time as a student with all the things I was able to do besides my study. I would like to use this opportunity to thank various people for the last couple of years.

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Rens Pieterse

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List of abbreviations

AH	Albert Heijn
BT	An order picker (vehicle) that is used to drive around with the load carriers
CPI	Crate Pick Installation
CUs	Cost Units
DC	Distribution Center (Warehouse)
DCP	Distribution Center Pijnacker
DCT	Distribution Center Tilburg
DCZ	Distribution Center Zaandam
DCO	Distribution Center Zwolle (Overijssel)
EPT	Earliest Production Time
ETS	Earliest Time on Staging lane
HOVA	Goods kept under pressure(Houders Onder druk) , Fats (Vetten) and Aerosol
HSC	Home Shop Center
LDC	National Distribution Center (Landelijk Distributie Centrum)
LDT	Latest Dropping Time
LTS	Latest Time on Staging lane
RDC	Regional Distribution Center
VBA	Visual Basic for Applications
WMS	Store Management System (Winkel Management Systeem)

Glossary

Dubbelloop	We talk about dubbelloop if a load carrier is dropped on a staging lane that is still in use by a trip of the previous cycle. This results in load carriers of two different trips placed on one staging lane, which is not preferred.
Load Carrier	A load carrier is used to move goods from one point to another point. Albert Heijn uses roll cages, rollies, dollies and displays to transport the ordered goods to the stores. The different types of load carriers are described in Appendix II.
Order	An order consists of all goods that are ordered by the store and delivered to the store at one point in time. We can distinguished orders for ambient goods, cooled goods, frozen goods and goods delivered by the bakery.
Trip	A trip consists of all orders that can be combined in one truck that is delivered within one route. This means that one truck delivers at least one order to at least one store.
Production	In this research the term “production” represents the picking of a load carrier. So, *production process* is equivalent to *order picking process*.
Collo	In this order pick area goods are picked on roll cages. The area contains ambient goods in boxes and plastic wraps. The largest proportion of order picking happens here.
Rolly	A type of load carrier. The different types of load carriers are described in Appendix II.
Dolly	A type of load carrier. The different types of load carriers are described in Appendix II.

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1 | Introduction

1.1 | Research context

1.1.1 | Ahold Delhaize

Ahold Delhaize is established in 2016 and arose from a merger of Ahold and Delhaize Group in 2016. It is a "world-leading food retailer with 6500 stores worldwide and 375,000 people, serving 50 million satisfied customers a week" (Ahold Delhaize, 2017a). It is active in the United States, Europe and Southeast Asia and contains supermarkets, convenience stores, online delivery, pick-up points, hypermarkets, specialty stores and gasoline stations (Ahold Delhaize, 2017b).

In the Netherlands, Ahold Delhaize has over 2,000 stores and distribution centers (DCs) and is the leading supermarket company, leader in specialty stores and e-commerce company. The Dutch brands of Ahold Delhaize consists of AH, ah.nl, AH to go, bol.com, Etos and Gall & Gall. These brands resulted in net sales of €12.7 billion in 2015 (Ahold Delhaize, 2017c).

1.1.2 | Albert Heijn

AH is founded in 1887 and has grown to be the largest supermarket chain in the Netherlands. Currently, the brand possesses 995 stores in the Netherlands and this number is still growing (Ahold, 2015). Among these stores around 40 per cent are franchised. It also has some stores in Belgium and Germany. According to IRi (2017) the total market share of AH grew from 35.1 per cent in 2015 to 35.4 per cent in 2016. The company's mission stated by its founder AH:

"Het alledaagse betaalbaar, het bijzondere bereikbaar"
(The everyday payable, the extraordinary reachable)

The brand has four different types of stores. The first and most familiar one is the neighborhood stores. These stores are based on regular grocery shopping and the products are influenced by the neighborhood and the region of the store. The second type is the AH XL, an extra-large supermarket for the bigger grocery trips. It has more choice in products and more parking places. The AH to go is the third type of store AH has. The AH to go concept is created to serve customers while travelling and offer them refreshments for the road. The last and newest type of store is the online store where you can order your products 24/7. You can either have your groceries delivered at your house, or you can get your groceries at one of the Pick Up points.

1.1.3 | Supply chain of Albert Heijn

The supply chain of AH is controlled by both their own and outsourced DCs. AH owns one national DC (LDC), which is located in Geldermalsen, and four regional DCs (RDCs). The RDCs are located in Pijnacker (DCP), Tilburg (DCT), Zaandam (DCZ) and Zwolle (DCO). The LDC processes around 11,500 ambient products, whereas the RDCs process both ambient (toilet paper, chocolate, soup etc.) and cooled products (vegetables, cheese, milk etc.). The slower moving products are stored in the LDC and the fast moving products are stored in the RDCs. The outsourced DCs are located in Bleiswijk, Hoogeveen, Oss and Zeewolde. The locations are shown in Figure 1.1.

Figure 1.1 Map of the DCs of AH

Suppliers deliver goods to the LDC and RDCs. These goods are unloaded at the docks and put on the staging lanes assigned to inbound transport. A general example of these staging lanes at a DC of AH is shown in Figure 1.2 and is explained in detail in Section 2.1. The products are then placed in the warehouse to be picked by the order pickers. After an order is picked by an order picker, the load carriers are put on the staging lanes assigned to outbound transport. The terms order picking and production are interchangeably used in this research and both mean the placing of goods on load carriers for an order. When the truck is docked, the truck is loaded and leaves to its destination.

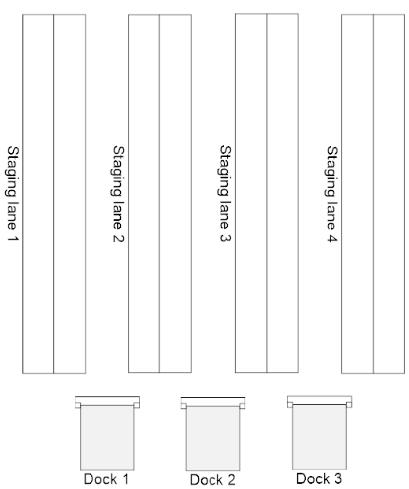


Figure 1.2 Example of the layout of staging lanes at a DC of AH

The orders picked in the LDC are transported to the RDCs or one of the four Home Shop Centers (HSC: Almere, De Meern, Eindhoven and Rotterdam). The load carriers for the RDCs are ready to go to the stores immediately, so they are treated as transit when getting to the RDC. AH uses the word "transito" for this flow. At the RDC the same process as in the LDC takes place. Goods from suppliers are delivered at the inbound staging lanes and moved to the warehouse where they wait to be picked.

When the orders are picked the load carriers are put on the right staging lanes. The difference between this process at the LDC and RDCs is that the transito is combined at the staging lanes in the RDCs. When the whole order is complete and the truck is docked, the loading process starts.

After the loading process, the truck driver drives to the store(s) to deliver the goods. Each store has to be delivered within an assigned one hour timeframe, which is predetermined by the logistics department. The number of stores that can be delivered in one trip depends on the number of load carriers per store, the location of the stores and the timeframe in which the orders need to be delivered at the stores. After unloading the load carriers, the driver takes the returns, the returns consists of empty load carriers, empty totes, cartons etc. The driver does this for every store in the trip, and after the trip the driver goes to a depot of a third party to drop off the returns.

The supply chain is graphically shown in Figure 1.3.

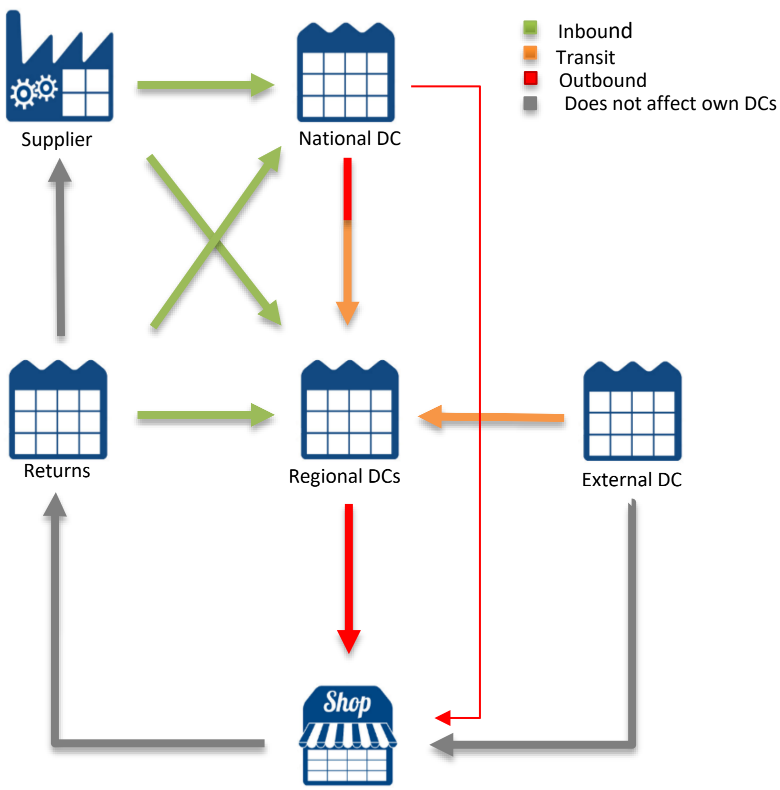


Figure 1.3 Overview supply chain AH

1.2 | Problem statement

The needs of the stores are the point of focus for AH. Therefore, warehouses have to adapt their processes in a certain way to those needs. Every store wants to be supplied at, in their eyes, the best time. These times slightly differ per store, but overall follow the same structure. Namely, when the younger part-time employees are available to stock the shelves (before or after school hours) and not during prime time. In addition to these wishes, some local laws lead to constraints for the delivery times, such as not allowing trucks in city centers at certain time windows.

In the current situation, the National Warehouse and Regional Warehouses are making use of staging lanes, for inbound, outbound and transito flows. This means that each truck is loaded or unloaded from a preassigned area next to the dock. The function of a staging lane is preset for a certain timeframe, so when a staging lane is assigned to be an outbound lane, it is only used for loading. The capacity of a staging lane is fixed and is as big as the maximum number of load carriers that fit in the biggest truck. Load carriers are dropped by the order picker immediately after an order is completed in the order picking process. This means that all the order picking for a trip has to happen right before the trip when the load carriers can be dropped on the assigned staging lane.

The combination of those wishes, constraints and the fixed number of staging lanes and docks, results in a fluctuating production during the day. This results in congestion and peaks in the production, loading and unloading process. To deal with these peaks in production, the logistics support department together with the transport department tries to level these peaks as much as possible. This is done to make sure that the capacity of the staging lanes is enough for the production (outbound), inbound and transito flows. However, this results in fluctuating and costly production schedules for the DCs. To reach the needed number of trips in the morning a big proportion of the production has to happen during the night, which raises the employee costs.

Problem statement

''The current flexibility and planning of the production is limited to the capacity and the use of the staging lanes, which makes the production schedule fluctuating and costly. There is a need for a framework that shows the effects of decoupling the production process and the dropping of the load carriers at the staging lanes using a marshalling area and determines the required size of this area.''

1.3 | Research objective and approach

Scope

Because of the numerous flows (inbound, outbound and transito) and product groups (cooled and ambient products), the research focusses only on the outbound flows of ambient products that are order picked within the warehouse. The transito flows are also not taken into account in this research, since this will not directly influence the production process of the DC itself. The order picking system is not in scope of this research and will not be changed. As well as the schedule of the departure times of the outbound trips, which will not be changed.

Research objective

The goal of the research is to create a framework that can be used for every AH warehouse. To validate the framework, a case study is performed at DCO. The research objective can be stated as follows:

"To create a general framework that shows the effects of decoupling the production process and the dropping of the load carriers at the staging lanes by making use of a marshalling area and determines the required size of this area."

To reach this objective, we first need to answer a set of sub-questions. Each of the sub-questions is linked to a chapter in which the sub-question is answered.

1. *What is the current situation of the processes between production and dropping of the load carriers at the staging lanes in the warehouses and which challenges currently occur in these processes?*

   In Chapter 2 we start with a review on the current processes at the DCs of AH. We map the process from order to delivery and pay special attention to the staging lanes. Next to that, we look into the fluctuating production figures during the year, week and day. We discuss the current utilization of the staging lanes and the cost of order picking. The research on the current situation leads us to the challenges of the current production process.

2. *What does the available academic literature say about flow in warehouses and what can we find about marshalling areas used in similar cases?*

   Chapter 3 contains a literature study to determine what the literature says on the flow in warehouses. We search for available literature on buffers used in practice that is comparable to the marshalling area we want to implement.

3. *How can we create a general framework that is usable for the DCs of AH and gives an insight in the effects of using a marshalling area on the flexibility and costs of the production process?*

   Chapter 4 describes the created general framework that calculates the required size of the marshalling area and shows the effects on the production process. We start with a general introduction of the framework, followed by the pseudocodes. We list all the parameters used in the framework and explain the output. We finish this chapter with a framework verification and validation.

4. *What would be the required size of the marshalling area if the framework is performed for DCO and what would be the effect of this marshalling area on the production process?*

   In Chapter 5 a case study is performed at DCO using the framework created in Chapter 4. The case study shows, by performing different scenarios, the effects of a marshalling area on the production process of DCO compared to the current situation. Each scenario contains different input settings, to be able to see what kind of effect the different settings have on the production process of DCO, the costs of order pickers, the standard deviation of order pickers in the order picking process and the minimum required size of the marshalling area at DCO.

5. *What are the potential benefits and challenges of decoupling the production process and the dropping of the load carriers at the staging lanes by making use of a marshalling area?*

   In Chapter 6, we first discuss the outcomes of the scenarios stated in Chapter 5. We use these outcomes to be able to say something about the influence of a marshalling area on the production process. Next to that, we come up with some potential additional benefits for the DCs and the stores. Followed by some topics that should be considered before implementing a marshalling area. We also mention some limitations to the results of this research.

Approach

The approach of this research is based on the answering of the created sub-questions. The order in which we perform this research is similar to the order of these sub-questions and is stated Table 1.1.

Step	Containing	Used data sources
1	Analyses of the current situation	Interviews with employees, observations of the process and data analyses of historical data
2	Literature review	Scientific articles
3	Develop of the general framework	Based on output of step 1 and step 2
4	Case study at DCO	Based on output of step 3
5	Discuss results of case study and benefits of a marshalling area	Based on the output of step 4

Table 1.1 Approach of the research

1.4 | Deliverables

The aim of this research is to deliver the following:

- A general data-driven framework that calculates the required size of a marshalling area and shows the effects on the flexibility and costs of the production process. The framework should be usable for every DC of AH.
- A case study on DCO that shows the framework is usable and determines the required size of the marshalling area at DCO.

2 | Current situation

This chapter describes the current processes from production to loading for outbound flows in detail for each warehouse to get a clear understanding of the current situation. We used information gained from meetings with employees and observations at the DCs. In Section 2.1 the flow from order to delivery is described. In Section 2.2 a detailed look at the staging lanes is given. Section 2.3 shows the current utilization rate of the staging lanes. In Section 2.4 the night and day production ratio and the costs of order picking are explained. We end this chapter with a conclusion in Section 2.5.

2.1 | Ordering and production figures

2.1.1 | From order to delivery

The DCs are always in operation, except from Saturday 11:00 p.m. to Sunday 05:00 a.m. During this timeframe the maintenance on the IT systems takes place. The order picking at the LDC takes place 24/7 in three working shifts. The order picking at the RDCs takes place in two shifts, a night shift and a day shift. Outside order picking hours, among other things cleaning, inbound deliveries from suppliers and the reallocation of products within the picking area take place.

The fulfilment of store orders happens for most stores from Monday to Saturday, however some stores get a delivery on Sunday as well. Every sixteen weeks, the transport department releases a schedule including all trips for these weeks. Only weeks with special days, like Eastern and Christmas, are excluded in this normal schedule and a special schedule is created for these weeks. The schedule contains fixed timeframes of one hour in which a store needs to receive its order.

All the ambient orders arrive at the system between 12:00 p.m. and 11:45 p.m. The order time depends on the delivery time of each product group the next day. The internal lead time (time between ordering and delivery) depends on the type of product and the location the product is stored (RDC, LDC or external DC). The lead time for products that have to be delivered from the LDC or an external party is longer than the lead time for products directly delivered from one of the RDCs. All orders are gathered in a system that creates the most efficient order picking routes using the orders that are released in the system at the same moment in time. The number of orders released depends on the capacity of the DC and the delivery of inbound stock from suppliers.

At the Earliest Time on Staging lane (ETS) the staging lane is released for load carriers to be put on. A staging lane is released either when the shift starts and the staging lane is not assigned to a trip yet or when the previous trip planned on that staging lane is loaded. From this moment onwards the staging lane can be filled with load carriers intended for the preassigned truck. The Latest Time on Staging lane (LTS) is the last time load carriers can be put on the staging lane, and is fifteen minutes before the truck driver has to start loading. This fifteen minutes is used as a safety slot, in case some of the load carriers are still being picked. Therefore when the orders are released, the planner has to make sure that all the order picking is ready and all load carriers are placed on the right staging lane before the LTS. After loading, the truck driver is able to start its trip.

The transport department makes the trip schedule based on predicted data using historical numbers of load carriers sent to each store. This means that the exact number of load carriers may differ from the predicted one. When the actual order comes in, the transport department checks if the number of load carriers for a certain trip still fits in the scheduled truck. If not, the trip needs to be changed by combining different deliveries or creating extra deliveries. This takes around one and a half hour. To make sure all load carriers fit in the truck, not completely filled load carriers are combined to reduce the number of load carriers sent to the stores. An example of two trips can be found in Appendix I.

2.1.2 | Staging lanes

Essentially the layout of the staging lanes are the same at each DC, however there are some minor differences between the staging lanes amid the DCs and within a DC. In general each dock has two staging lanes on each side of the dock. However, due to the specific layout of a DC and the difference in size between docks and staging lanes, this does not count for each dock.

Another difference is the size of the staging lanes. The size of a staging lane is related to the maximum number of load carriers that can be put on that staging lane. It is not possible to schedule a trip with a bigger scheduled load on a staging lane that does not fit all the load carriers of that trip. Most staging lanes are as big as the total load carriers that fit in the biggest truck used by AH. Besides the size of the staging lanes, the layout differs as well. The staging lanes are divided into two, to six areas. This deviation is used to be able to make a distinction between the stores within a trip. If, for example, a staging lane is divided into two areas ("a" & "b") and a trip contains two stores, the load carriers of one store are placed on the "a" area and the load carriers of the other store are placed on the "b" area. This is done to make sure that the load carriers will be loaded in the right order into the truck. At the LDC the load carriers are not sorted per store, this is done at the RDC.

The number trips and thus the number of load carriers of these trips, that can be produced and put on the outbound staging lanes is limited to the number of outbound staging lanes. Each trip is scheduled on a (part of a) staging lane and dock. The first trip of the day (the trip with the earliest LTS) is scheduled at the first dock and the first outbound staging lane. The trip with the second

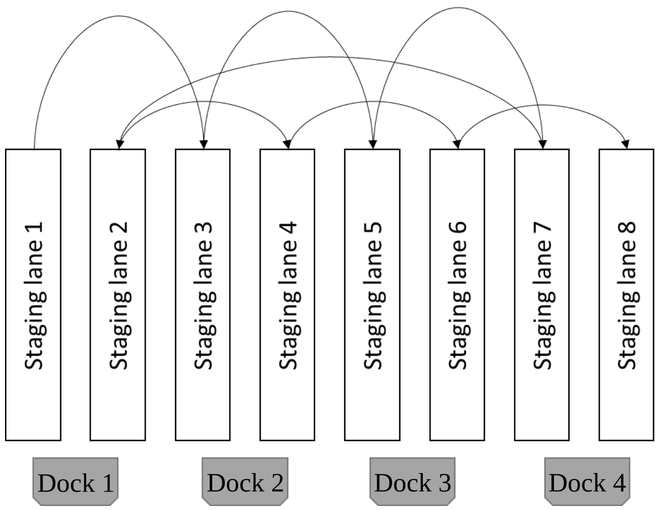


Figure 2.1 Representation of one cycle

earliest LTS is scheduled on the second dock and the first outbound staging lane. If all docks are assigned to a trip, the next trip is scheduled on the second staging lane at the first dock etc. A total round of assigned trips is called a cycle. A representation of a cycle is shown in Figure 2.1. The next cycle starts again at dock one, staging lane one. This method makes sure that, even if the staging lanes are not perfectly spread over the docks, any problems of trucks needed to be loaded at the same dock at the same time will be minimized.

If we take a look at the production of the load carriers during a cycle, the arriving of the load carriers at the outbound staging lane cannot happen before the load carriers of the previous cycle on that staging lane have been loaded. As explained in the previous section, a staging lane is released when the previous planned trip on that staging lane is loaded. However, due to a lack of capacity or delays of trucks it can happen that load carriers of the next cycle arrive at the staging lanes before the staging lanes are emptied. AH uses the term *dubbelloop* for this event. If this happens and the load carriers will not fit on the staging lane anymore, the load carriers are put outside the dedicated area of the staging lane. This can result in unsafe situations, due to containers placed on the main road between the staging lanes area and the order picking zone. Furthermore, walking paths might be barricaded and load carriers can be misplaced at other staging lanes. Misplaced load carriers could cause delays if they are not easily found.

The number of outbound staging lanes determines the number of trips, and thus the number of load carriers, that can be produced at a certain timeframe. The situation of not being able to upscale the production due to capacity restrictions at the staging lanes and the wishes of the stores regarding delivery times, makes the production process very fluctuating. This fluctuating production process is shown in the following sections based on the data of 2016.

2.1.3 | Production during the year

In Figure 2.2 the relative production numbers of 2016 are presented, in which a 100 per cent represents the week with the maximum number of load carriers produced. The production numbers include the automatic production of load carriers with beer crates on the Crate Pick Installation (CPI) at the RDCs and the automatic order picking on the Triple-O in DCP. These automated processes are explained in further detail in Section 2.2. The graph shows a strong fluctuation during the year, with a difference of almost 32 per cent between the minimum (week 13) and maximum week (week 51). This fluctuation in the number of goods produced can be explained due to different reasons. Special days, like Eastern and Christmas, increase the demand of products in the stores and thus lead to an increase in the number of goods that need to be picked in the DCs. Special days can also lead to some exceptional opening hours and delivery times, which can lead to fluctuations in the production schedule. Besides special days, special promotions can increase the demand of products in a certain week, e.g. the Hamsterweken and Route 99.

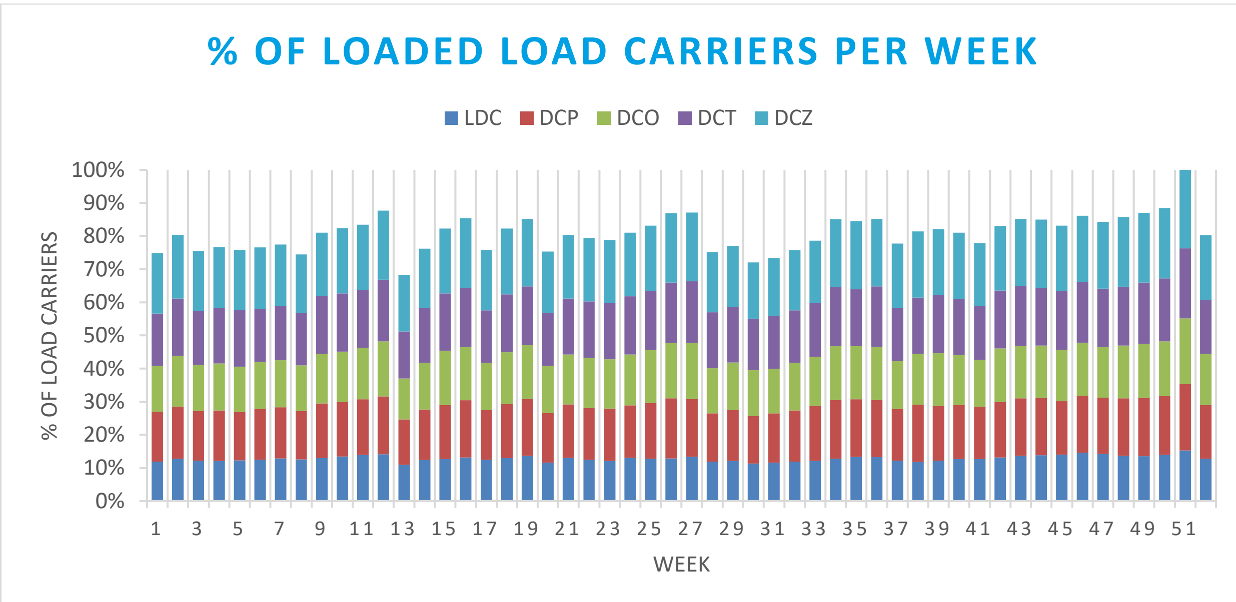


Figure 2.2 Comparison of total loaded load carriers per week in 2016 (maximum week is set at 100 per cent)

If we look at the fluctuation for each DC we can even see a 38 per cent fluctuation in loaded load carriers at DCO, this also means a fluctuation of 38 per cent of the number of load carriers that are placed and handled at the staging lanes.

2.1.4 | Production during the week

Figure 2.3 shows the average number of produced load carriers for each day of the week in percentages of the total produced number of load carriers in the entire week per DC. We assume a production day is from 11:00 p.m. to 11:00 p.m. the next day. We can conclude that the number of load carriers fluctuates during the week. We can see an increase in the average number of load carriers from Monday to Saturday for the RDCs, Monday has a total average number of produced load carriers of 14.4 per cent and Saturday 19.5 per cent. This difference is even bigger for DCO, which has a difference of 8.2 per cent between Monday and Saturday. Sunday has the least number of produced load carriers. The LDC shows different production figures during the week, namely a decrease in the average number of produced load carriers during the week, with a small peak on Friday. This fluctuation in production figures has also its influence on the use of the staging lane, more produced load carriers results in more load carriers handled at the staging lanes in the same timeframe.

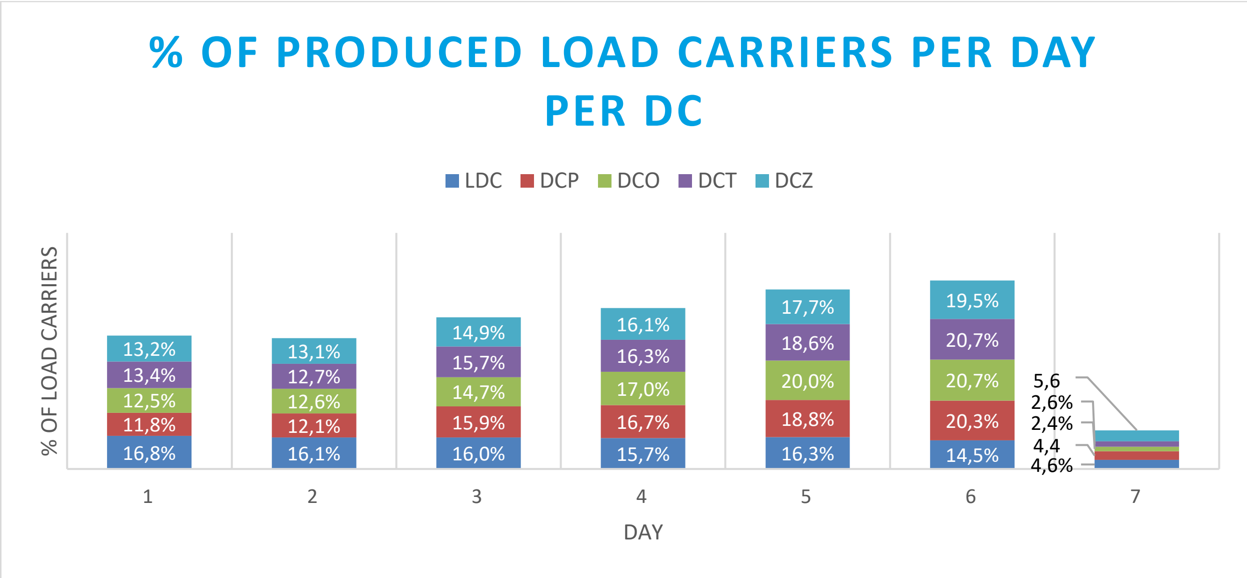


Figure 2.3 Average percentage of total produced load carriers during the week per DC in 2016

2.1.5 | Production during the day

If we look at the production during the day at the LDC, graphically shown in Figure 2.4, we see a relatively evenly distributed production process. The graph shows the average load carriers picked per hour compared to the average total number of load carriers picked during the day. During the night the production is slightly lower than during the day. We can see some lower production rates during shift changes around 07:00 a.m. and around 03:00 p.m. and around breaks 03:00 a.m., 12:00 p.m. and 05:00 p.m.

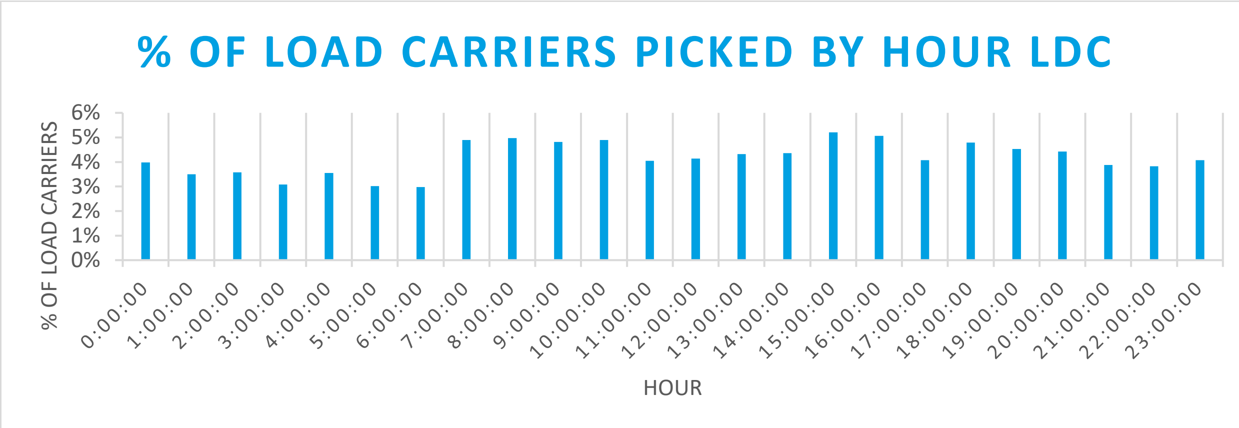


Figure 2.4 Average percentage of produced load carriers over the day in 2016 at LDC

The production process at the RDCs is much more fluctuating, as can be seen in Figure 2.5. During the night the production is lower than the production during the day and after 05:00 p.m. the production is almost zero. Including a peak of 8.4 per cent between 10:00 and 11:00 and 0.2 per cent between 09:00 p.m. and 10:00 p.m. We can see some lower production rates during shift changes around 07:00 a.m. and around 03:00 p.m. and around the breaks at 03:00 a.m. and 12:00 p.m. If we compare each RDC, we can conclude that in general the patterns look similar. The only mayor difference is the extra evening shift at DCZ. Also from the fluctuating production process during the day, we can conclude that number of load carriers arriving on the staging lanes is not equally divided during the day. During peaks, a lot of produced load carriers are brought to the staging lanes. While on the other hand during low production hours, the number of produced load carriers brought to the staging lanes is way less.

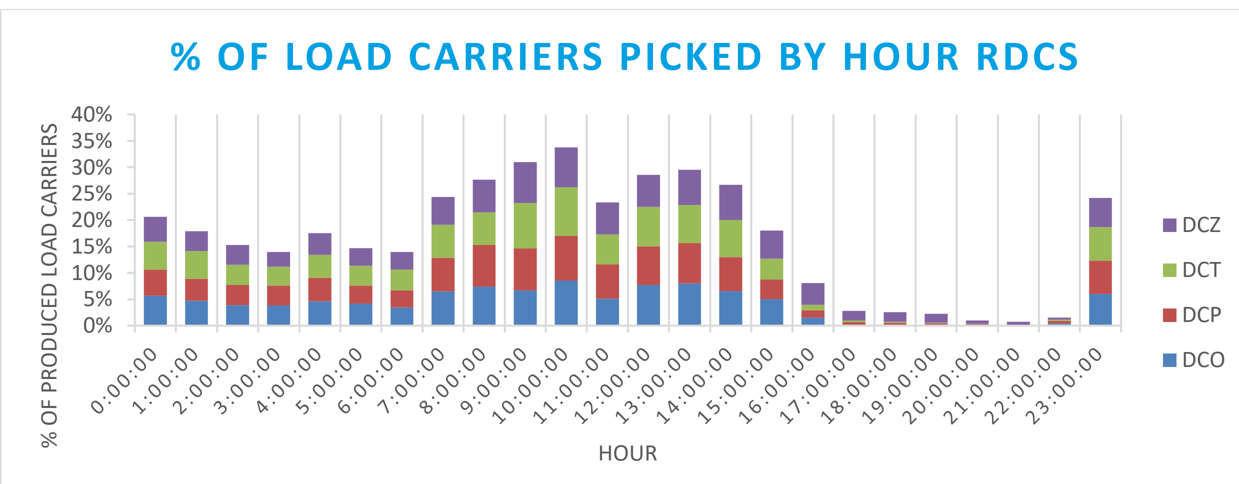


Figure 2.5 Average percentage of produced load carriers during the day in 2016 in RDCs

2.2 | Different flows to the staging lanes

We can distinguish different flows of load carriers to and from the outbound staging lanes. Those are shown graphically in Figure 2.6, including the section where each flow is described in detail. There are four types of staging lanes, namely inbound, outbound, transito and passingen. A staging lane can only be dedicated to one of these types in a certain timeframe, however the purpose of a staging lane can change during the day. As the names suggest, inbound staging lanes are used for inbound flows, outbound staging lanes are used for outbound flows and transito staging lanes are used for transito flows. Passingen are outbound staging lanes that are not assigned to a trip in the trip schedule. Those staging lanes are only used if an extra trip needs to be deployed due to a difference in the predicted and the actual number of load carriers for a trip. The newly created trips are scheduled on the passingen staging lanes. Since we only focus on the outbound flow in this research, we limit ourselves to the outbound and passingen staging lanes. Thus from now on, the term staging lanes is used to describe the outbound and passingen staging lanes.

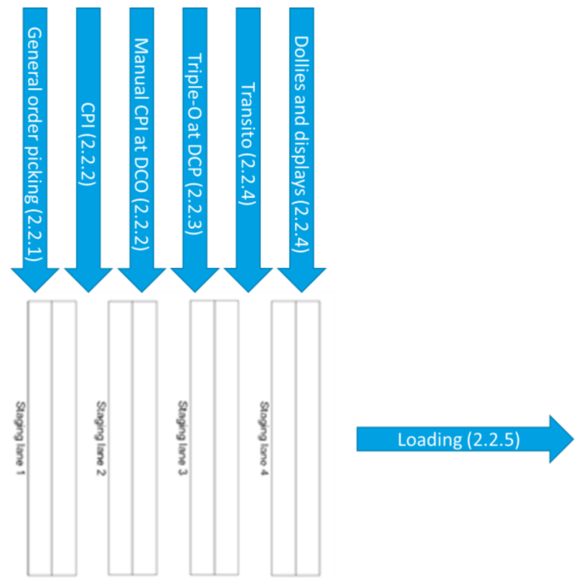


Figure 2.6 Flows to and from the outbound staging lanes

2.2.1 | General order picking process

The order picking area is divided into different order picking zones. The layout of these order pick zones are different for each DC. Each order picking zone has its own order picking time and both the type of load carrier and goods picked can differ per order picking zone. Appendix II contains sizes and pictures of each load carrier. Most of the order picking happens on roll cages and contains goods in boxes and plastic wraps. This zone is called the *collo* area. Besides these order picking zones, LDC has some additional order picking zones. In these zones, products are picked in totes. This can be a tote containing one product or combining different products by placing them in one tote. Products in totes are placed on a *rolly*, this is a different type of load carrier. In general all products within an order picking area are placed in the order from heavy and non-compressible to light and compressible. The RDCs contain two separate areas, a cooled area for the cooled products and a normal area for the ambient products. However, the cooled area is not within the scope of this research.

The orders formed by the order pick system are established based on the optimal route in the warehouse using the orders of the trips that are released at the same time. Therefore, the load carriers picked at the same time by one order picker do not have to be for the same trip, but are formed as efficient as possible. This is done by the “Pick Order Build” algorithm and can form 30 picking orders of maximum five load carriers at a time [1]. This algorithm makes combinations of load carriers from the 30 orders with the earliest LTS. An order picker picks five load carriers at the same time, so before starting five empty load carriers are needed. The place where empty load carriers are stored is different for each DC. After getting those empty load carriers, the order picker starts picking the order. In general all the order picking is done by voice-driven picking. After the order is picked the order picker prints the labels and sticks them on each load carrier.

After sticking labels to the picked load carriers, it differs per order picking area what happens next. In the *collo* area the order picker drops the roll cages at the right staging lane. The order picker does this by removing a certain load carrier from the order picker[2] (BT) and dropping it on the closest available position from the dock at the right staging lane. After dropping the load carrier, the order picker walks back to its BT and drives to the staging lane where the next load carrier has to be dropped. The containers are dropped in a logical order, to minimize the travel distance between the staging lanes. If all load carriers are dropped, the order picker gets a new order. Products picked on *rollies* are combined at a specially assigned area in the LDC. After combining, the load carriers are provided with a lit and put in a machine for strap binding. This makes the load carriers stronger and less theft sensitive. After this process, the load carriers are combined per trip and brought to the right staging lane.

Initial promotions

Every DC has special aisles assigned to “initial promotions” and “after delivery of promotions”, this is a different order picking zone. One side of the aisles in this zone contains the initial promotions goods and are products that will be in sale next week. The initial promotion for a store is already known two to three weeks in advance. The other side of the lane is filled with after delivery of promotions products and exists out of goods that are in sale the current week. The load

---

[1] A picking order contains a maximum of five load carriers. The IT systems used to run the “Pick Order Build” can perform the algorithm in a few minutes if a maximum of 150 load carriers is in the system. This means that 30 (150/5) picking orders can be formed at a time.

[2] An order picker is a vehicle used by the order pickers to pick an order. Since this can cause any confusion, from now on the abbreviation BT (the brand of the vehicles) is used.

carriers picked in this area only contain goods on sale and are not combined with goods from the regular order picking zones.

2.2.2 | Crate Pick Installation

Each RDC has a CPI which automatically creates full roll cages with beer crates. The machine automatically unloads beer crates from the incoming pallets and puts them on different aisles. Another machine stacks the beer crates on roll cages. The CPI can only handle completely filled roll cages with just one type and brand of beer. This means the CPI is only used for the most common brands and for beer that is on sale. DCO has, besides the CPI, two manual controllable tools that order pickers can use to produce roll cages with beer crates. These tools are used if the CPI has not enough capacity to produce the needed number of roll cages with beer in time. Roll cages with beer that are pre-produced are placed in a temporary buffer.

2.2.3 | Triple-O DCP

DCP has a small area which is partly mechanized, called the Triple-O. This machine handles inbound pallets and automatically stores them in a separate warehouse in the building. If a certain product is needed from the buffer, the pallet is picked and the needed number of layers with goods are automatically removed. The products go into another warehouse, where every product is stored in aisles. Whenever a certain number of products is needed, the system releases the products and transfers them to the right roll cage. Here an employee is stacking the products into another machine that automatically goes down every time the employee is done with a layer of products. If all products of an order are put into the machine, the machine automatically lowers the products on a roll cage. If five roll cages are done, an employee takes the roll cages using a BT to the right staging lanes. Currently there are 290 product candidates that can be handled by the Tripple-O. The current maximum Triple-O capacity per module is 40,000 goods during the night and afternoon shift and 25,000 goods during the day shift. Since the machine exists out of two modules, the total current maximum capacity per day is 130,000 goods a day.

2.2.4 | Transito and dollies & displays

There are multiple transito flows going through the supply chain of AH. The internal transit flow refers to the load carriers that are picked in the LDC and transferred to the RDCs. These load carriers are ready to be transported to the stores directly. The load carriers are not sorted per store before going into the truck at the LDC, which means the RDCs get the load carriers not sorted. At the RDC, the truck arrives at one of the transito staging lanes. The external transit flows are the flows from external parties directly to the RDCs.

Each RDC has a dedicated area for the storage of *dollies* and *displays*. *Dollies* are load carriers that contain one type of soda and can be placed directly into the store. The *dollies* are prepared at the supplier and do not need any handling activities at the RDC. *Displays* on the other hand, are load carriers with special goods or promotions. The flow of *rollies* and *displays* at the RDC can be compared to the transito flow.

2.2.5 | Loading

The truck is loaded with the load carriers that are put on the assigned staging lane. This is always done by the driver and one or two employees of AH. Each truck contains a barcode, this barcode is scanned to make sure the right truck is at the right dock. Two load carriers can be moved into the truck at the same time using a hand pallet truck. Every time after scanning a label of a load carrier the barcode of the truck needs to be scanned. Preventing load carriers to be loaded in the wrong truck. If a load carrier is not at the staging lane before the scheduled departure time, the transport department of AH is called to ask if it is possible to send that load carrier with the next transport with the same destination. If not, the truck has to wait until the load carrier is found. This can cause delayed delivery times.

2.3 | Utilization of staging lanes

In this section the utilization of the staging lanes in each DC are discussed. To calculate the utilization rate and the number of load carriers placed on the staging lanes, scheduled and predicted data of 2016 is used.

Using goods produced per week, we can define a minimum, maximum and an average week for each DC. The minimum is the week with the lowest number of picked goods, the maximum is the week with the largest number of picked goods and the average is the week with the smallest difference between the number of picked goods during a week and the average of picked goods during the whole year 2016. A production week is from Saturday 10:55 p.m. to next week Saturday 10:55 p.m. Week 27 is excluded from the data[3]. Table 2.1 shows the minimum, maximum and average week for each of the DCs.

[3] Week 27 of 2016 is not taken into account, since this week is not representative due to a system failure.

DC	Minimum	Maximum	Average
LDC	Week 30	Week 51	Week 8
DCO	Week 13	Week 51	Week 7
DCP	Week 13	Week 51	Week 1
DCT	Week 13	Week 51	Week 11
DCZ	Week 30	Week 51	Week 33

Table 2.1 Minimum, maximum and average production week in 2016

Week 13 is the minimum at three of the RDCs, since this week includes Eastern Monday and a lot of stores are closed on this day. Week 30 is during the summer holiday, therefore the demand of goods is less than normal. Week 51 is the maximum, because this is the week before Christmas.

The average utilization of the staging lanes is shown in Table 2.2, based on the predicted and scheduled produced number of load carriers per trip. The average utilization represents the total area that is used during the week at the outbound staging lanes. The table shows that the utilization of staging lanes over the week never exceeds 32 per cent. The utilization rate is based on two variables, the time the staging lane is actually used and the number of load carriers scheduled for a trip. We suppose that containers are picked and placed on the staging lanes at the same speed during order picking times between the ETS and LTS (e.g. if a trip contains ten containers and the dedicated staging lane is reserved for an hour, the number of containers put on the staging lane is 0.17 per minute). We suppose that all staging lanes assigned to trips that finished loading in the same hour are emptied equally divided during the hour. Since the load carriers of a trip consists mainly out of roll cages and this type of load carrier has the biggest surface, we use this size for each of the produced load carriers. The average utilization rate is calculated as follows:

$$\text{Utilization Rate} = \frac{\begin{array}{c}(scheduled\ number\ of\ load\ carriers\ at\ the\ end\ of\ the\ previous\ hour\ on\ staging\ lanes \\ +0.5*scheduled\ production\ during\ the\ hour \\ -0.5*number\ of\ scheduled\ load\ carriers\ in\ departed\ trucks\ in\ that\ hour) \\ *\ the\ surface\ of\ a\ roll\ cage\ (0.66*0.8)\end{array}}{total\ surface\ of\ outbound\ staging\ lanes\ dedicated\ to\ outbound\ transport\ in\ that\ hour}$$

A graphical representation of the utilization can also be found in Appendix III. Since the utilization graphs of each week for each warehouse are quite similar, only the graphs of the utilization of the stating lanes at DCO at the maximum week are shown. The graphs show the highs and lows during the week per hour. It can be concluded that, using the predicted and scheduled produced number of load carriers per trip, the average utilization of an hour never exceeds 48 per cent. This means that even during a peak hour the total average use of the available space at the staging lanes is lower than half of the reserved area for outbound transport.

We can conclude that the average utilization is the highest in the maximum week, except for DCT. Besides that, we can see a highly fluctuating utilisation during the day. During evening hours the utilisation of the staging lanes is zero (except for Saturday nights, since the load carriers for Sunday are not picked during the night).

DC	Minimum week	Maximum week	Average
DCO	24%	31%	28%
DCP	29%	32%	32%
DCT	25%	26%	27%
DCZ	29%	32%	29%

Table 2.2 Average utilization of outbound staging lanes in the min., max. and avg. week in 2016 for the RDCs based on delivery schedule

2.4 | Night and day production ratio

The logistic department tries to create its schedule in such a way that only 33 per cent of the production happens during the night and 66 per cent during the day. This is to save employee costs, since working during the evening and night hours leads to a surcharge. The surcharge per hour is obtained from the current collected labour agreement and is shown in Appendix IV. Table 2.3 shows the ratio between the average percentage of picked load carriers during night (11:00 p.m. until 07:00 a.m.) and day (07:00 a.m. until 11:00 p.m.), which shows that this ratio is close to 33 per cent at all DCs.

	LDC	DCO	DCP	DCT	DCZ
Night	27.78%	36.39%	33.95%	36.50%	31.24%
Day	72.22%	63.61%	66.05%	63.50%	68.76%

Table 2.3 Average percentage of picked load carriers during the day and night for each DC in 2016

However, the employees in the DCs of AH are ageing. The collective employment agreement of AH states:

"*Voor werknemers van 58 jaar of ouder bestaat er geen verplichting meer om in ploegen-dienst te werken.*" (Albert Heijn, 2016)

This implies that all employees who are 58 years or older can choose themselves if they want to work shifts or not. As a result of this entitlement, many employees stop working shifts. This means that there are many employees shifting from the night shift to the day shift, which causes more and more pressure on the day production.

2.5 | Conclusion

In this chapter we reviewed the current process form order to delivery and focused mainly on the staging lanes. There are four types of staging lanes, namely inbound, outbound, transito and passingen. A staging lane can only be assigned to one type of flow during a timeframe. The number of outbound staging lanes determines the trips, and thus the number load carriers, that can be produced. The situation of not being able to increase the production due to insufficient capacity at the staging lanes and the wishes of the stores regarding delivery times makes the production process very fluctuating.

From the historical data of 2016 we concluded that the production during the year fluctuates strongly, with a difference of almost 32 per cent between the overall minimum (week 13) and maximum week (week 51). If we look at the fluctuations during the week, we can see an increase of 5.5 per cent of the total average number of produced load carriers from 14.4 per cent on Monday to 19.5 per cent on Saturday. During the day we can also see a strong variation in the number of produced load carriers at the RDCs. The largest peak in the production process is between 10:00 a.m. and 11:00 a.m. with 8.4 per cent of the total daily production. The minimum production takes place between 09:00 p.m. and 10:00 p.m. and is only 0.2 per cent of the total daily production. These fluctuations in production have a direct effect on the use of the staging lanes.

We concluded that, using the predicted and scheduled produced number of load carriers per trip, the average utilization at the minimum, average and maximum week never exceeds 32 per cent. This means that the current space reserved for outbound staging lanes is on average only used for 32 per cent. This low utilization rate can be explained by the highly fluctuating production. If we look at the desired night and day production ratio, we can conclude that two out of five DCs achieve this ratio and the rest of the RDCs are close. However, due to ageing employees more and more employees decide to stop working shifts. This results in a shift of employees from the night production to the day production.

3 | Literature

In this chapter, Chapter 3, a literature study is performed. Section 3.1 describes terms, flows and efficiency in warehouses in general. In Section 3.2 re-sequencing buffers are introduced. Section 3.3 contains the conclusions of this chapter.

3.1 | General terms

If we take a look into the literature, De Koster, Le-Duc and Roodbergen (2007) state there is a difference between the terms *warehouse* and *distribution center*. According to them, the term *warehouse* is used when the main function is the buffering and storage of goods. While the term *distribution center* is used if distribution is the main function of the warehouse. Van den Berg and Zijm (1999) refer to a *distribution warehouse* if products from different suppliers are collected in the warehouse and sent to different customers. In this research all these terms are interchangeable used to refer to a combination of buffering, storage and the distribution of goods. The functions and flows of a typical warehouse are shown in Figure 3.1. The main activities of a warehouse can be distinguished into four categories. *Receiving* is the first activity and includes the unloading of goods from the inbound trucks and the checks whether these goods are delivered as agreed. The second activity is *storage* and refers to the storage of the received products in the warehouse. The process of retrieving the right products is called *order picking.* This involves not only the picking of the goods, but also the process of combining and scheduling the customer orders, slotting of goods in the order picking area, the releasing of the orders to the order pickers and the dropping of the picked articles at the shipping area (De Koster et al., 2007). The last activity is the *shipping* of the products to the customers.

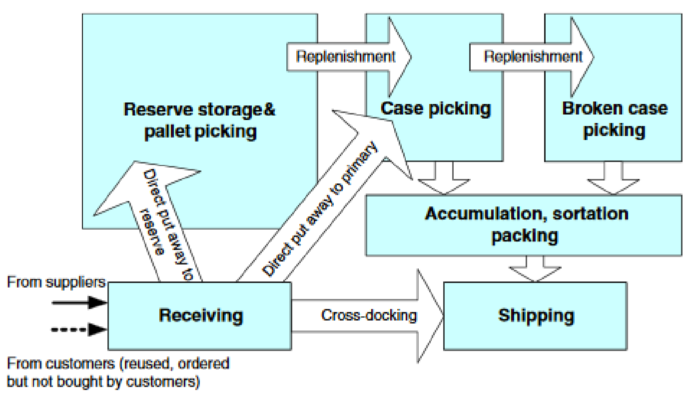


Figure 3.1 Functions and flows in a typical warehouse (Tompkins, White, Bozer, Frazelle, & Tanchoco, 2010)

An *order* refers to a list of *stock keeping units* (SKUs) and is a combination of all articles ordered by one customer. We can distinguish different order picking systems, from which *picker-to-parts* systems are mostly used in a *manual warehouses*. A *manual warehouse* requires humans to do the order picking and means that the order picker walks or drives through the aisles to pick items from their location in the warehouse. If the order picking area is large and thus the distances between the products is too big to walk, the order picking generally happens using an order picker. In this research we will use the term *BTs* for order picker trucks to prevent confusion with the employees driving the order picker trucks. While *parts-to-picker* systems are used more often in automated warehouses (Koster, 2004). In a *parts-to-picker* system, the items are retrieved automatically by storage and retrieval systems (AS/RS) and brought to the order picker.

To be able to compete against the other big supermarket chains it is important to keep the costs of handling products as low as possible and serve costumer needs in the best way possible. Supermarket chains try to achieve high-volume production and distribution, while having as little as possible inventory throughout the supply chain and deliver the goods as fast as possible (van den Berg & Zijm, 1999). The costs of a warehouse can be divided into the main activities discussed before and are shown in Figure 3.2.

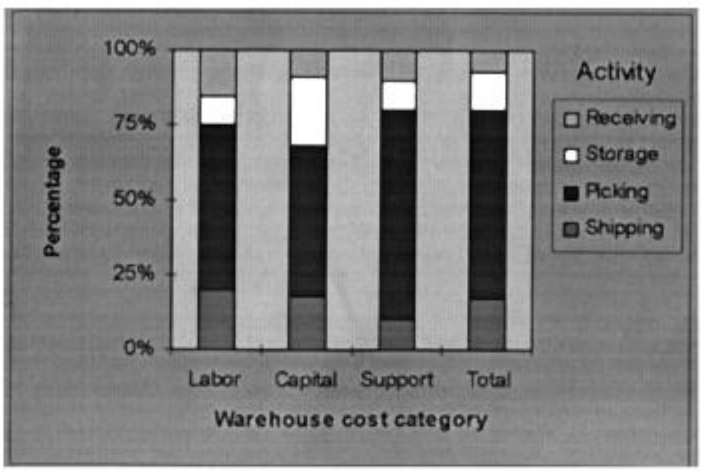


Figure 3.2 Warehouse costs per activity (van den Berg & Zijm, 1999)

Research showed that the order picking is the most costly operation (more than 60 per cent), then shipping, then storage and the least costly is the receiving process. The efficiency of order picking needs to be improved nowadays, since customers want to receive their products as fast as possible. The time required for picking an order includes the time for traveling between the order picking locations, the actual picking of the products and activities as dropping off the products and packaging (Dekker, de Koster, Roodbergen, & van Kalleveen, 2004). Travel time is, regarding Thomkins et al. (2010), usually the most time consuming of these activities. The travel time between docks should not only be based on the travel distance, but should also include the possible congestion. This congestion can lead to higher labor costs, due to longer order picking times, and delays in the shipment of the goods (Bartholdi III & Gue, 2000).

3.2 | Re-sequencing buffers

In the automotive industry, the sequence of the vehicles that are built in the factory determines the efficiency of the final assembly process (Inman, 2003). Regarding Gusikhin, Caprihan and Stecke (2008) parallel workstations, stochastic processing times, limited process capabilities in successive workstations and required rework on parts, can result in parts that are delayed during the production or assembly process. This delay may cause the output sequence to be different from the desired input sequence. Boysen, Scholl and Wopperer (2012) mention four buffer solutions used in mixed-model assembly lines to deal with this disrupted sequence, which recover the desired sequence before the products are sent to the final assembly. These four buffer types are graphically shown in Figure 3.3.

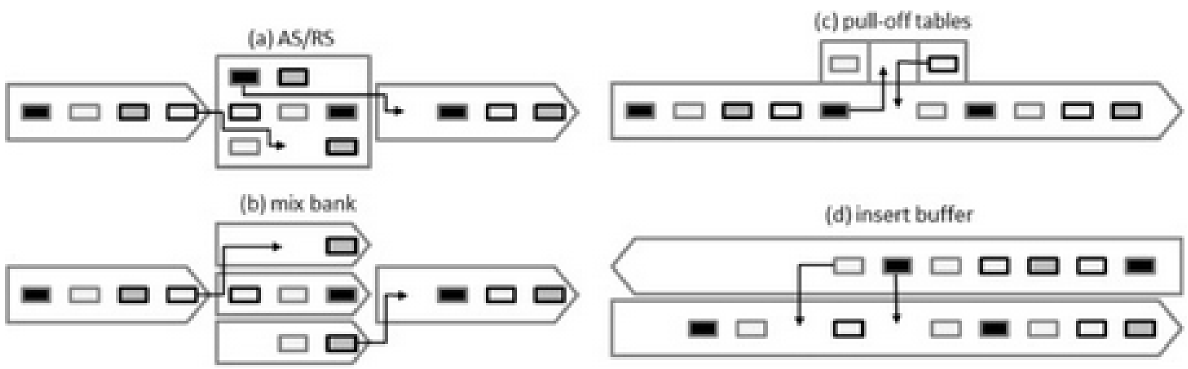


Figure 3.3 Four buffer types (Boysen, Scholl, & Wopperer, 2012)

The first option is to make use of an automated storage and retrieval system. The second possibility is to add parallel lanes, named mix bank, to the process. A mix bank exists out of multiply lanes, where each lane acts like a separate queue. A part can be assigned to a certain lane where it has to wait in line until all parts in front of that part are released. This can be compared to the first in, first out principle. Thirdly, pull-off tables can be added to the process. This buffer can temporarily hold a part, so that the other parts on the line can move forward until the part is placed back into the process. The last option is to use an insert buffer. This buffer exists out of two conveyor belts that are moving in opposite directions. Parts from one conveyer can be placed between the parts on the second conveyer. All these solutions can be seen as a temporary buffer to store the parts that have to wait, so the delayed part can pass. Figure 3.4 gives a graphical overview of an assembly process, including this buffer. Gusikhin, Caprihan and Stecke (2008) use the term re-sequencing buffer for this type of buffer.

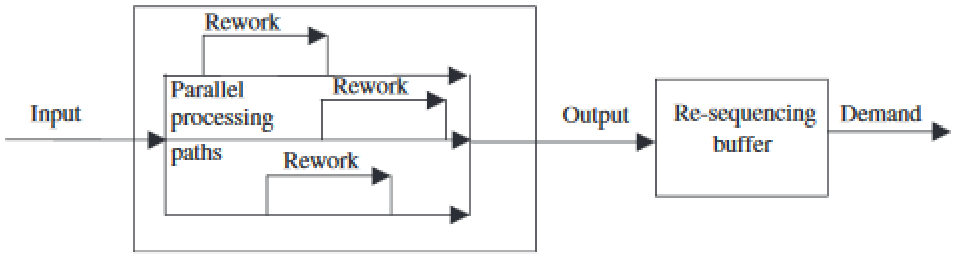


Figure 3.4 Overview of the assembly process including the re-sequencing buffer (Gusikhin, Caprihan, & Stecke, 2008)

3.3 | Conclusion

In this research we touch three of the main activities at a warehouse, namely storage, order picking and the shipping. However, the storage in our case is not the storage of goods before the order picking but the storage of goods after the order picking and before the shipping. This extra storage can decouple the order picking process and the shipping process. From the literature we concluded that 60 per cent of the total costs can be assigned to the order picking process. Thus, this would be the most interesting activity to focus on when reducing costs in the whole process.

Since there is not a lot of literature on marshalling areas and the effects of decoupling the order picking process and the loading process yet, we tried to find comparable situations described in the current available literature. In the automotive industry re-sequencing buffers are placed just before the final assembly to be able to recover the desired sequence. These buffers are comparable to a marshalling area. Despite that the main reason of adding a re-sequencing buffer to the assembly process is not similar to the main reason of adding a marshalling area to the process, the concept is quite similar. Load carriers stored in the marshalling area have to get out of the marshalling area in a certain sequence to be able to get the right load carriers at the right time. However, the load carriers that are placed inside the marshalling area are already finished and ready for loading. While the re-sequencing buffer is placed along the assembly line or just before the final assembly.

4 | Framework

This chapter describes the developed framework to determine the required size of the marshalling area for the desired production process. In Section 4.1 a general introduction to the framework is described as well as the developed pseudo code. In Section 4.2 the elements of the framework are described. The created algorithms of the framework are explained in Section 4.3. Section 4.4 discusses the output of the framework. Section 4.5 and Section 4.6 contain the verification and the validation of the framework respectively.

4.1 | General introduction to the framework

Calculating the size of the marshalling area

The required size of the marshalling area depends on the desired production planning. To calculate the required size we take the maximum surface of load carriers that is stored at the marshalling area at the same time during the production week. The number of load carriers stored at the marshalling area at a certain point during the production week equals the total number of produced load carriers at that point in time minus the total number of loaded load carriers until that same point in time. If we know the number of load carriers at the marshalling area, we can calculate the corresponding surface by multiplying this number by the surface of the load carriers.

Since we use the current transport schedule, we cannot change the loading time of the trucks. Since this will influence the delivery time of the shops and the costs for transport (both will increase if the loading time increases). Thus, in the created framework the loading time and the departure times of the trucks remain the same.

We can distinguish two types of load carriers stored at the marshalling area, namely load carriers for the general orders and beer load carriers. The production of general load carriers during a certain timeframe depends on the number of regular- and initial promotions load carriers that needs to be and can be picked, the number of order pickers during that timeframe and the order pick time of the load carriers. The beer production depends on the number of beer load carriers that needs to be produced and the capacity of the CPI, the Manual CPI and the by hand production. In case of DCP we have a third type of load carrier, namely the load carrier that is produced using the Triple-O.

We can split a production week into different timeslots. The number of load carriers on the marshalling area at timeslot *t* is calculated as follows:

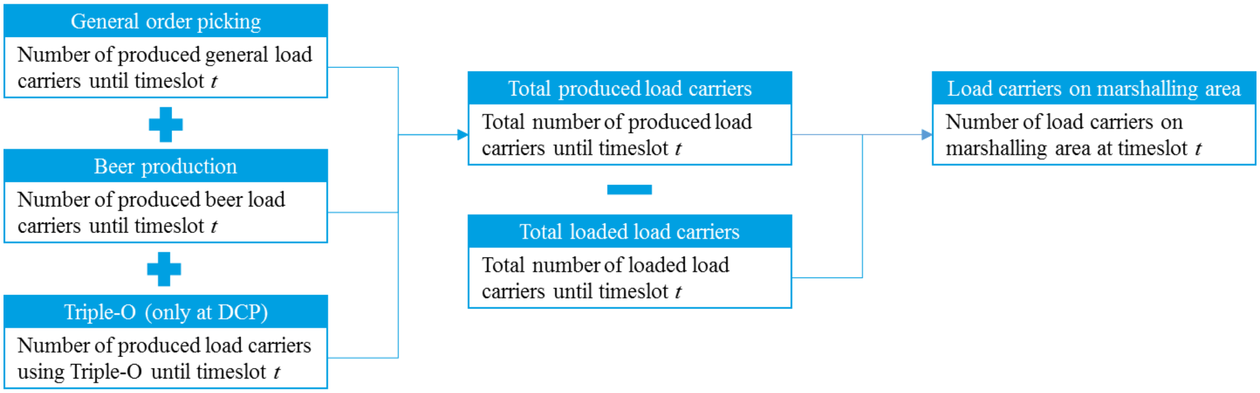


Figure 4.1 Calculation of number of load carriers on marshalling area

The number of produced general load carriers at timeslot t depends on the number of order pickers at timeslot t. We can calculate the number of produced load carriers at timeslot t by multiplying the number of order pickers at timeslot t with the total number of load carriers picked by one order picker during a timeslot. The number of load carriers picked per order picker during a timeslot can be derived from the average order pick time. The production in timeslot t is calculated as follows:

$$Production\ in\ timeslot\ t =$$

$$number\ of\ order\ pickers\ at\ timeslot\ t\ *$$

$$\frac{timeslot\ in\ minutes * 5\ (number\ of\ load\ carriers\ picked\ at\ the\ same\ time\ by\ one\ order\ picker)}{average\ order\ pick\ time\ (per\ 5\ load\ carriers)}$$

Objective

The objective of the framework is to find the required size of the marshalling area given a production planning that minimizes the total employee costs of order picking and is as evenly distributed as possible.

A timeslot t is either open for order picking and beer production or closed. As discussed in Section 2.4 each order pick hour has its own order pick costs obtained from the current collected labour agreement. This means that we can assign costs to each timeslot and we know exactly which timeslots are open and the cheapest to produce in. For the general order picking we try to produce the load carriers as cheap as possible, this means that we always try to produce them in the cheapest available timeslot possible. If there are multiple timeslots with the lowest possible order picking costs, we try to evenly distribute the order picking over these timeslots. The production of beer load carriers happens just in time, since the beer load carriers will be picked by just a few employees (controlling the CPI, manual CPI(s) or picking by hand). This means we do not take the costs of a timeslot into account and we always try to produce the beer load carriers just before the loading of the truck takes place.

It is preferable to produce all beer load carriers using the CPI. If the capacity of the CPI is not sufficient to produce all beer load carriers in time, we try to pre-produce the load carriers using the CPI (if pre-production is allowed). If the capacity of the CPI using normal production and (possibly) pre-production is still not sufficient to produce all beer load carriers, we use normal production and (possibly) pre-production using the manual CPI(s) to produce the remaining beer load carriers. The last option is to produce beer load carriers by hand.

The production of load carriers on the Triple-O at DCP is a different type of process and is, in the first place, comparable to the production of beer load carriers. The Triple-O has also a maximum capacity per hour and we try to produce the load carriers that can be produced using the Triple-O, as late as possible. If the capacity of the Triple-O is not sufficient to produce all the load carriers that can be picked using the Triple-O (both regular and initial promotions load carriers), the remaining load carriers are produced the same way as the general load carriers.

Timeframe of producing an order

As discussed in Subsection 2.1.1, in the current situation each order has an ETS and a LTS. A staging lane has to be empty before the first load carrier of the next cycle on that staging lane arrives. However, if the production starts too early and a load carrier is dropped at the staging lane before the previous trip is loaded, *dubbelloop* occurs. Since *dubbelloop* is undesirable, the load carriers of an order cannot be done before the ETS of that order. The LTS of an order is the latest possible time of the load carriers of that order arriving at the staging lanes to be sure they are on time for the loading of the truck. Each order contains three different types of load carriers we take into account in this research, namely regular load carriers, initial promotions load carriers and beer load carriers.

In the new situation the ETS of an order is replaced by the Earliest Production Time (EPT). Since the production is not limited to the number of staging lanes anymore but to both the ordering time of the stores and the time the transport department needs to finish the operational scheduling of the trips. The EPT of the regular load carriers of an order equals the ordering time of the store plus the time the transport department needs to finalize the schedule. So:

$$\begin{aligned}&EPT\ regular\ load\ carriers\ of\ an\ order\\&\qquad = ordering\ time\ of\ the\ store + the\ time\ the\ transport\ department\ needs\end{aligned}$$

The EPT of the initial promotions load carriers of an order depends on the start time from which initial promotions can be picked and can be stated as follows:

$$EPT\ initial\ promotions\ load\ carriers\ of\ an\ order = start\ time\ picking\ initial\ promotions$$

The EPT of the beer load carriers of an order depends on the fact if pre-production is possible or not. If pre-production is not possible the EPT is the same as the EPT of the regular load carriers of an order. However, if pre-production is possible, the EPT of the beer load carriers of an order equals the start time of pre-production and can be stated as follows:

$$EPT\ beer\ load\ carriers\ of\ an\ order = start\ time\ pre-production$$

The LTS of an order can be replaced by the Latest Dropping Time (LDT) and is the same for the regular load carriers, the initial promotions load carriers and the beer load carriers. Since, load carriers have to be dropped at the marshalling area before a certain time to make sure the load carriers are ready in time to be loaded. Since we do not want to change anything in the departure time of the trucks, the LDT of an order depends on the start loading time of that order, the time the load carriers need to be processed in the marshalling area and the safety time. The formula of the LDT is as follows:

$$LDT\ of\ an\ order = start\ time\ of\ loading - processing\ time\ on\ marshalling\ area - safety\ time$$

An example of the EPT and LDT for one type of load carrier is graphically shown in Figure 4.2.

The first timeslot where production can take place is the timeslot which contains the smallest EPT of all trips. By summing up the number of load carriers for each order with an EPS in the same timeslot, we can determine the total number of load carriers that can be picked from a certain timeslot onwards. We can do this for each type of load carrier. This is shown on the left bottom sight of the figure. For example, the EPT of Order 1 and Order 2 lay between 03:30:00 p.m. and 03:59:59 p.m., this means the total load carriers that can be produced from that timeslot onwards equals the sum of the load carriers of Order 1 and Order 2 (36 + 14 = 50). We can do the same for the LDT, by summing up the load carriers of each trip with a LDT in the same timeslot, we know exactly how many load carriers have to be dropped at the marshalling area before a certain timeslot. This is shown on the right bottom sight of the figure. For example, the LDT of Order 2 and Order 3 lay between 06:00:00 a.m. and 06:29:29 a.m. This means that the number of load carriers that has to be picked before that timeslot equals the total number of load carriers of Order 2 and Order 3 (14 + 25 = 39). With this knowledge, we know precisely how many load carriers of each type can be and have to be produced between two timeslots.

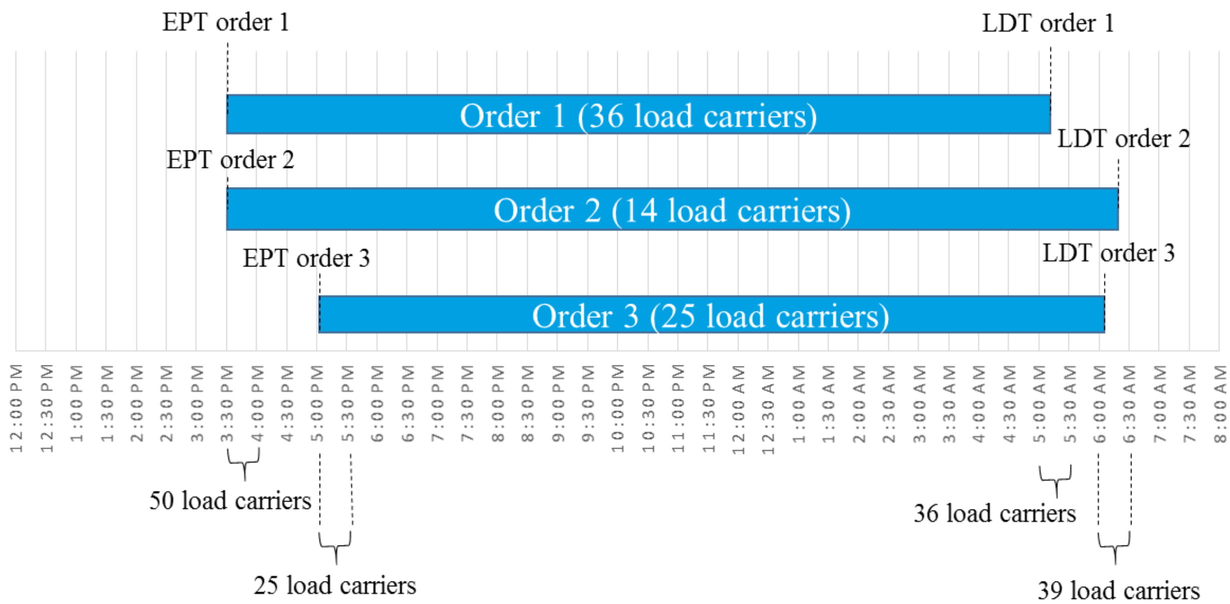


Figure 4.2 Example of orders including the EPT and LDT

Average order pick time

We will use an average order pick time as an input for the framework. This average order pick time differs per DC and is based on the average order pick time of five load carriers picked at the same time. This means that an order picker always picks five load carriers at the same time. The current average order pick time is based on data of 2016. The new average order pick time can be adjusted as an input variable.

Pseudo codes

To develop the algorithms for the framework, we first created pseudo codes. These pseudo codes can be found in Appendix VI.

4.2 | Framework elements

This section describes all the elements that have to be included in the framework. The first step of creating the framework is to define the different stages. The decision variables and parameters are stated in Subsection 4.2.1. An example of the input screen of the Excel Tool can be found in Appendix VII. The restrictions and constraints are described in Subsection 4.2.2.

4.2.1 | Notation

Indices

i	Type of load carriers (i =1,2)	1 = regular, 2 = initial promotions
j	Production type (j = 1,2,..,6)	1 = CPI, 2 = pre-production CPI, 3 = manual CPI, 4 = pre-production manual CPI, 5 = by hand, 6 = pre-production by hand
t	Timeslot (t = 1,2,….)	1 = 00:00:00 – 00:29:59, 2 = 00:30:00 – 00:59:50, etc.

Order picking general orders

Decision variable	
OP_{it}	The number of order pickers producing load carriers type i in the process at timeslot t. The number of order pickers at timeslot t determines the production at timeslot t.
Parameters	
$StartNumLCi_{it}$	Number of load carriers of type i that can be produced from timeslot t onwards
$FinishNumLC_{it}$	Number of load carriers of type i that has to be produced before timeslot t
MaxOP	The maximum number of order pickers in the production process at the same time.
$Open_t$	States whether timeslot t is open for order picking.
AvgOPT	The average order pick time of an order (picking 5 load carriers at the same time).
$Cost_t$	Cost of an order picker at timeslot t

Beer production

Decision variable	
BLC_{jt}	The number of produced beer load carriers using production type j (1 = CPI, 2 = pre-production CPI, 3 = manual CPI, 4 = pre-production manual CPI, 5 = by hand) at timeslot t.
Parameters	
$StartNumBLC_t$	Number of beer load carriers that can be produced from timeslot t onwards
$FinishNumBLC_t$	Number of beer load carriers that has to be produced until timeslot t
CapCPI	The capacity of the CPI per half an hour.
CapManCPI	The maximum capacity of one Manual CPI per half an hour.

NumManCPI	The number of Manual CPIs.
MaxHandProd	The maximum number of beer load carriers that can be produced by hand per half an hour.
$Open_t$	States whether timeslot *t* is open for order picking.

Production on Triple-O at DCP

Decision variable	
$TRIPLC_{it}$	The number of produced load carriers of type *i* at timeslot *t*
Parameters	
$StartNumTRIPLC_{it}$	Number of load carriers of type *i* that can be produced from timeslot *t* onwards
$FinishNumTRIOLC_{it}$	Number of load carriers of type *i* that has to be produced until timeslot *t*
CapTRIP	The capacity of the Triple-O per half an hour.
$Open_t$	States whether timeslot *t* is open for order picking.

4.2.2 | Restrictions and constraints

A few constraints have to be included into the framework.

Order picking general orders

1. An order cannot be picked before the EPT (the total production of load carrier type *i* until timeslot *t* cannot exceed the total $StartNumLC_{it}$ until timeslot *t*).
2. An order cannot be done after the LDT (the total production of load carrier type *i* until timeslot *t* cannot be smaller than the total FinishNumLC*it* until timeslot *t*).
3. The total number of order pickers in the production process at timeslot *t* cannot exceed MaxOP.
4. The number of order pickers in the system at timeslot *t* cannot be negative and should be integer.
5. Order picking cannot happen at closed timeslots.

Beer production

1. An order cannot be produced before the EPT (the total production of beer load carrier until timeslot *t* cannot exceed the total StartNumBLC*t* until timeslot *t*).
2. An order cannot be done after the LDT (the total production of beer load carrier until timeslot *t* cannot be smaller than the total $FinishNumBLC_{it}$ until timeslot *t*).
3. The number of produced beer load carriers using the CPI (general production and pre-production) at timeslot *t* cannot exceed CapCPI.
4. The number of produced beer load carriers using the Manual CPI (general production and pre-production) at timeslot *t* cannot exceed CapManCPI multiplied by the NumManCPI.
5. The number of produced beer load carriers by hand (general production and pre-production) at timeslot *t* cannot exceed MaxHandProd.

6. Pre-production on CPI, manual CPI and by hand is only possible if pre-production is turned on.
7. The number of produced beer load carriers for each production type at timeslot *t* cannot be negative.
8. The beer production cannot happen at closed timeslots.

Production on Triple-O at DCP

1. An order cannot be produced before the EPT (the total production of load carrier until timeslot *t* cannot exceed the total StartNumTRIPLC*t* until timeslot *t*).
2. An order cannot be done after the LDT (the total production of load carrier until timeslot *t* cannot be smaller than the total $\text{FinishNumTRIPLC}_{it}$ until timeslot *t*).
3. The number of produced beer load carriers using the Triple-O (regular and initial promotions load carriers) at timeslot *t* cannot exceed CapTRIP.
4. The production cannot happen at closed timeslots.

4.3 | Algorithms

The algorithms described in this section creates a production schedule that minimizes the total employee costs of order picking and is as evenly distributes as possible. We use a heuristic to solve this problem, since the problem is simple enough to be solved by the created algorithm in Virtual Basic for Applications (VBA) in Excel. We choose to use Excel to create the framework, instead of any other optimization program, due to the fact that AH already uses Excel and is therefore able to adapt the framework as desired. Furthermore, input variables are easily changeable in Excel using the created input screen and the output of the algorithms is shown in a simple but clear dashboard.

4.3.1 | Order picking general orders

First the order pickers for producing the regular orders are assigned to the timeslots. Since the initial promotion is known before the regular orders and thus has a larger timeframe in which the initial promotions load carriers can be produced, the initial promotions can be used to fill up the gaps in the created production schedule. To create the production schedule for the regular orders, the algorithm starts at the last timeslot of the week and searches for the last timeslot in which load carriers need to be finished ($\text{FinishNumLC}_1 > 0$). We start scheduling the total number of load carriers for trips with a LDT within that timeslot (timeslot *t*). Then the heuristic searches for the best suitable timeslot to produce in, using the following rules:

1. Checks whether the total production of load carriers is not enough yet (smaller than the FinishNumLC_1)

2. Checks whether the production is not happening before the release of the order (total production until that timeslot cannot be larger than the $StartNumLC_1$ until that timeslot)
3. Checks whether the timeslot is "open" for order picking
4. Checks whether the timeslot did not reach the maximum number of order pickers yet
5. Searches for the timeslot that is the least expensive
6. Searches for the timeslot that has the lowest number of order pickers already assigned to that timeslot

If a timeslot satisfies all above rules, this timeslot is selected and one order picker is added to the selected timeslot. After adding an order picker to the selected timeslot, the algorithm starts again at check one. If the algorithm cannot find a timeslot which satisfies all checks, the current input of the variables leads to an unfeasible solution and needs to be changed. If all load carriers of timeslot *t* are produced, the algorithm searches for the next timeslot in which load carriers need to be finished ($FinishNumberLC_1 > 0$). A flow chart of this algorithm can be found in Appendix VII.

After producing all the regular load carriers, the order pickers for producing the initial promotions load carriers are assigned to the timeslots. The used algorithm is basically the same as the algorithm used for the regular orders. However, now the scheduled number of order pickers for the regular orders have to be taken into account when scheduling the load carriers of the initial promotions. Since the total number of order pickers of both the regular load carriers and initial promotions load carriers within a timeslot cannot exceed the maximum order pickers in the production process at the same time. Besides that, the $StartNumLC_1$ and $FinishNumLC_1$ is changed to $StartNumLC_2$ and $FinishNumLC_2$.

4.3.2 | Beer production

As discussed in Section 4.1 there are multiple ways to produce beer load carriers. The fastest and easiest method to create beer load carriers is using the CPI. However, the CPI has a maximum capacity per hour. Which means that it could happen that the capacity is insufficient to produce all the beer load carriers in time. If that is the case, pre-production can be performed. If the pre-production is still not enough to produce all the beer load carriers, the Manual CPI is used. As a last resort beer load carriers can be produced by hand, but this is the least preferred option.

The algorithm for beer production can be divided into different steps. The first step is to execute the algorithm for the regular production on the CPI. The algorithm starts again at the last timeslot of the week and searches for the last timeslot *t* in which beer load carriers need to be finished ($FinishNumBLC_t > 0$). We start with the production of the total number of beer load carriers for orders with a LDT within that timeslot (timeslot *t*). Then the algorithm searches for the first available timeslot to produce in, using the following rules:

1. Checks whether the total production of beer load carriers is not enough yet (smaller than the $FinishNumBLC_t$)
2. Checks whether the production is not happening before the release of the order (total production until that timeslot cannot be larger than the total StartNumBLC until that timeslot)
3. Checks whether the timeslot is “open” for order picking
4. Checks whether the timeslot did not reach the CapCPI

If a timeslot satisfies all above checks, this timeslot is selected and half or one beer load carrier (depending on the capacity of the CPI) is added to the selected timeslot. After that, the algorithm starts again at the first check. If the algorithm cannot find a timeslot which satisfies the checks, not all of the beer load carriers can be produced using the CPI. The remaining beer load carriers have to be pre-produced, produced at the manual CPI or have to be produced by hand. If all load carriers of timeslot *t* are produced, the algorithm searches for the next timeslot in which load carriers need to be finished. A flow chart of this algorithm can be found in Appendix VII.

If the capacity of the CPI is not enough to produce all the orders, pre-production using the CPI is favorable. The algorithm for producing the beer load carriers using pre-production is basically the same as the algorithm for the normal beer production. Except for the EPT and the fact that the number of produced beer load carriers in the regular production process on the CPI have to be taken into account. The EPT is adapted to the earliest possible pre-production time and the total number of produced beer load carriers (both regular production and pre-production) in a timeslot cannot exceed the CapCPI.

After executing the algorithm for the normal production and pre-production (if pre-production is put possible) using the CPI, the algorithm is used to perform beer production using the manual CPI. This algorithm is exactly the same as the algorithm used at the CPI, but the maximum capacity is adapted MaxManCPI multiplied by the NumManCPI. The EPT is either the normal EPT as stated in the trip schedule or is adapted to the earliest possible pre-production time in case of pre-production.

If the capacity of the manual CPI is still not enough to produce the total number of needed beer load carriers, beer production by hand production is performed. The same algorithm can be used again. The only difference is that the maximum capacity is adapted to the MaxHandProd. The EPT is either the normal EPT as stated in the trip schedule or is adapted to the earliest possible pre-production time in case of pre-production.

4.3.3 | Production using Triple-O at DCP

The production on the Triple-O uses a combination of the algorithms explained above. The production on the Triple-O works the same way as the beer production, since we want to use the maximum capacity of the Triple-O and produce the load carriers as late as possible. This means we can use the beer production algorithm to determine the production on the Triple-O. However, as explained in Subsection 2.2.4, the Triple-O is not able to handle all the goods. This means that not all the load carriers of an order can be produced on the Triple-O.

The load carriers that can be produced on the Triple-O can be divided into regular load carriers and initial promotions load carriers. We first execute the beer production algorithm for the regular load carriers that can be produced on the Triple-O. We use the maximum capacity of the Triple-O per hour (CapTRIP), the $StartNumTRIPLC_{1t}$ and the $FinishNumTRIPLC_{1t}$. After performing the algorithm for the regular load carriers, the algorithm is performed for the initial promotions load carriers. The total number of produced load carriers in a timeslot, both regular and initial promotions, cannot exceed the CapTRIP. Now we use the $StartNumTRIPLC_{2t}$ and the $StartNumTRIPLC_{2t}$. If the capacity of the Triple-O is not able to produce all the load carriers, the remaining load carriers have to be picked by hand in the general order picking process.

The remaining load carriers and the load carriers that could not be produced using the Triple-O in the first place can be combined. The algorithm of the general order picking is performed for these load carriers. First the algorithm is performed for the regular load carriers using the MaxOP, $StartNumLC_{1t}$, $StartNumTRIPLC_{1t}$, $FinishNumLC_{1t}$ and $FinishNumTRIPLC_{1t}$. If the production planning of the regular load carriers is created, the algorithm is performed for the initial promotions load carriers. Now we use the $StartNumLC_{2t}$, $StartNumTRIPLC_{2t}$, $FinishNumLC_{2t}$ and $FinishNumTRIPLC_{2t}$. We have to take into account the scheduled number of order pickers for the regular orders when scheduling the load carriers of the initial promotions. Since the total number of order pickers of both the regular load carriers and initial promotions load carriers within a timeslot cannot exceed the maximum order pickers in the production process at the same time.

4.4 | Output

The production processes created by the algorithms will lead to the required size of the marshalling area. The required size of the marshalling area is represented both in the total number of load carriers and the size in square meters. An example of the output screen can be found in Appendix IX. As discussed in Section 4.1, the number of load carriers at the marshalling area at certain timeslot *t* is determined by the total number of produced load carriers up to and including that timeslot minus the number of load carriers that are loaded up to and including that timeslot. We take the finish loading time as the moment that all load carriers of a trip leave the marshalling area. We compare the newly created production planning with the current production planning on three main subjects, namely the required size of the marshalling area, the total costs of the order pickers and the standard deviation of the number of order pickers.

The costs are calculated using the number of order pickers at a timeslot multiplied by the costs in percentages of one order picker. For example, if we have a timeslot where 40 order pickers are working and that timeslot has a surcharge of 60 per cent the total costs of that timeslot is 6.4 Cost Units (CUs) (40*1.60 per cent = 6.4).

The standard deviation of the numbers of order pickers is calculated over the hours in which order picking actually takes place. The standard deviation can be used as a measurement to determine the fluctuations in the production planning. The smaller the standard deviation, the more evenly distributed the production planning. We can compare the standard deviation of the current production planning with the standard deviation of the new production planning to determine if the production planning got more evenly distributed.

4.5 | Framework verification

To check whether the framework gives accurate results, we have tested the framework using the settings of the current situation. When we do not change the current average order pick time, the total number of order pickers during the week in the new situation should be the same as the total number of order pickers in the current situation. Since the productivity does not change and the same number of load carriers has to be picked, the total time spent on order picking should be the same in both cases. Next to that, the total number of produced load carriers during the week should be the same in the current situation as in the new situation and the total number of produced load carriers should be the same as the total number of loaded load carriers.

To check whether the production of load carriers happens at the preferred available order pick hours (open for order picking, the cheapest and the lowest number of order pickers) and between the EPT and LDT the framework is tested with a few orders. These tested orders were manually selected and contained both normal orders and exceptions to make sure the framework was able to deal with all kind of orders. Manual calculations resulted in the same output as the framework.

4.6 | Framework validation

To validate the framework, we organized an expert session to discuss the output of the framework showing different scenarios. All comments on the previous framework and its output were taken into account and the framework is adapted to these comments. If we look at the output of the framework using the current production settings, we conclude that the outcomes regarding the size of the marshalling area is comparable to the current size of the outbound staging lanes. Next to that, the costs of order picking and the standard deviation of order pickers does not differ that much from the current situation. This means that the output of the framework is considered to be accurate.

5 | Case study DCO

In this section a case study is performed at DCO using the framework described in Section 4. Section 5.1 explains the current situation at DCO. In Section 5.2 multiple scenarios are described and performed using the framework. Section 5.3 gives an overview of the outcomes of the scenarios.

5.1 | Current situation DCO

5.1.1 | General order picking

Pick hours and number of order pickers

The current order picking at DCO happens in different shifts. From Monday till Saturday there is a night shift from 11:00 p.m. till 07:00 a.m. and the day order picking is done from 07:00 a.m. till 05:00 p.m. On Sunday there is only a day shift from 07:00 a.m. till 01:00 p.m. As described in Section 2.4 the average production at DCO during the day is 63.61 per cent and during the night 36.39 per cent, this is based on historical data of 2016. We will use this data to make an estimation of the employee costs of order picking at the current process. The maximum number of order pickers that can be placed in the order picking process at the same time is 105 (excluding fork-lift drivers for pick replenishment), according to the capacity planner of DCO. Besides the limited number of available BTs (around 105) there will be too much congestion if there are more than 105 order pickers in the order picking process at the same time. However, based on practical experience of the capacity planner of DCO, 95 order pickers are equally efficient as 105 order pickers. Thus, we can conclude that the maximum number of order pickers at the same time in the order picking process should not exceed 95.

Average order pick time

The average order pick time differs for each DC (shown in Appendix X). The average order pick time not only differs per DC, but is also different for each order picking zone. However, as stated in Section 4.1 we do not differentiate between the average order pick time for the different order pick zones as well as the number of load carriers picked at the same time. As an input for the current average order pick time we will use 55:49 minutes, which is based on the historical data on the picking of five load carriers at the same time.

To determine the average order picking time, historical data of 2016 is used. This raw data contains all voice-picking orders executed in 2016, including the start and end time. However, since this time includes possible breaks and does not show whether an employee took a break during a certain order, the average order picking time needs to be adapted. Thus, for all orders the real order pick time and the norm time is compared. The norm time is the pre-calculated time for each order and depends on the number of different goods within the order, the total number of goods within the order and the total driving distance. If during a certain time window most of the orders had a delay of at least 30 minutes, we assume that the break probably took place around this time window. All orders around this timeframe with a delay of at least 30 minutes (compared to the norm time) were adapted. The average order pick time still includes short coffee breaks.

Initial promotions

The production of the initial promotions in the current situation takes place from Wednesday onwards and is delivered to the store immediately.

5.1.2 | Beer production

DCO has one CPI with a capacity of around 41 load carriers of beer per hour. Next to the normal CPI there are two Manual CPIs that both have a capacity of around 25 load carriers per hour. DCO uses pre-production to make sure everything is produced in time. The pre-produced beer load carriers are placed on empty spots inside the building.

5.1.3 | Scenario 0: Current situation (base case)

Average week

If we use the above settings to make a representation of the current production process of an average production week (week 7) and calculate the total employee costs of the order picking process and standard deviation of the number of order pickers in the process we will get the following output. The graph below shows the current production process of week 7. The yellow line shows the number of order pickers in the production process. The number of order pickers is determined by calculating the total number of load carriers that needs to be produced within a shift (63.61 per cent during the day and 36.39 per cent during the night) using actual orders in week 7 dived by the average number of load carriers picked per hour. Each order picker picks five load carriers at the same time.

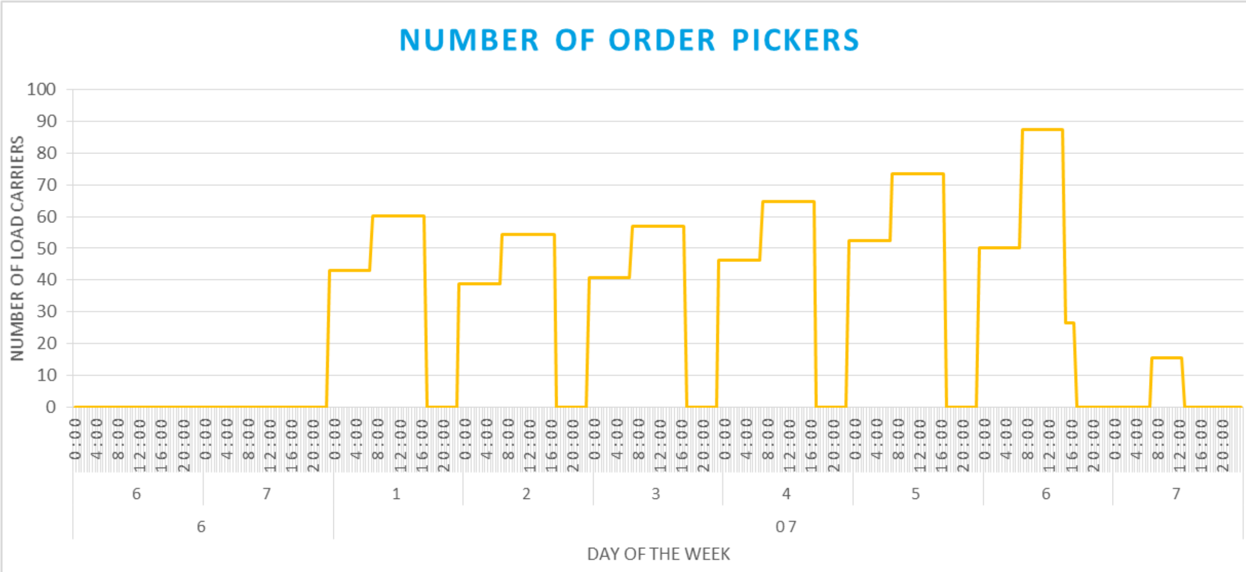


Figure 5.1 Current production process using data from week 7 at DCO

As discussed in Section 4.4, the costs of the current order picking process can be expressed in CUs. The costs of the current production process in week 7 is 14,911.02 CUs. If we take a look at the standard deviation of the number of order pickers of the current production process in week 7 is 16.19. We use these numbers to compare the newly created production planning including a marshalling area with the current production process.

Maximum week

If we change the production week from the average production week to the maximum production week (week 51) we will get a different output. The total employee costs of the current order picking process is 17,107.21 CUs and the standard deviation of the number of order pickers in the maximum week is 16.63. We use these numbers to compare the created scenarios using the maximum week with the current production planning.

5.2 | Scenarios

In this section we describe different scenarios for which the framework created in Chapter 4 is executed. From the output we can conclude what kind of influence different settings have on the production planning and thus the size of the marshalling area. The graphs of scenario 2 up to and including 9 are presented in Appendix XI.

5.2.1 | Scenario 1: Maximum number of order pickers (average week)

Settings

As discussed in Subsection 5.1.1 the maximum number of order pickers at the same time in the production process is 95, since a larger number of order pickers will make the production process inefficient. Thus, in this first scenario we will set the maximum number of order pickers at 95. For this scenario we will not change the current average order pick time.

The EPT of each order is set one and a half hour after the ordering time of the store (as discussed in Subsection 2.1.1. this is the time the transport department needs to fine-tune the trip schedule). In this first scenario we will not change any of the other settings. So the production of initial promotions starts on Wednesday. The available order pick hours will stay the same as in the current situation.

Output

If we execute the framework using the above settings we get the production planning in week 6 and 7 shown in Figure 5.2.

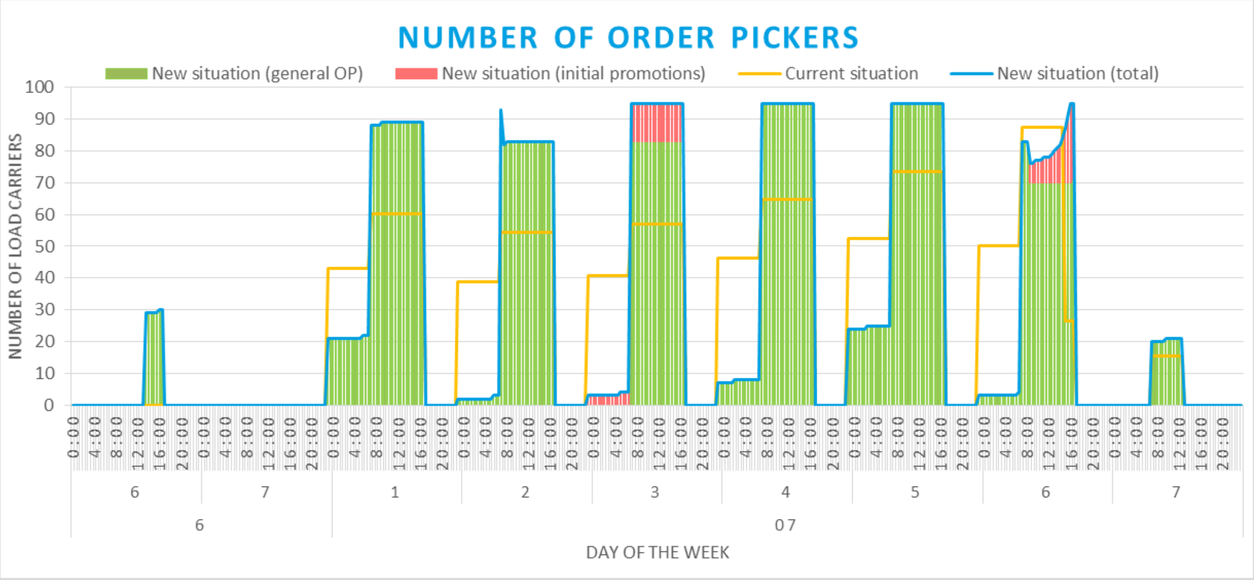


Figure 5.2 Production process scenario 1

The new production planning shows stronger peaks than the current production process. This can be explained by the fact that production mainly takes place during the least expensive production hours by as many order pickers as possible. The process also shows some unrealistic peaks, for example the peak of 93 order pickers on Tuesday between 07:00 a.m. and 08:00 a.m. This is caused by the fact that this is a cheaper hour to produce in than during the night and the order picking cannot happen after 8 a.m., since the orders and thus the load carriers have to be ready by then. In a real life situation the extra order pickers and the load carriers they produce would be spread out over the night and will result in a slightly higher total cost. However, this is such a small cost increase that it is negligible. If we would spread the additional ten order pickers of that hour through the night, we get an increase in CUs of 3.9 (10 * 0.39). The 0.39 can be explained by the surcharge of producing during the night and is 39 per cent. If we compare this to the total CUs in this scenario (13,664.94 CUs), it leads to an increase of only 0.03 per cent. The production of initial promotions mainly takes place on Wednesday and Saturday. The corresponding production of beer load carriers is shown in Figure 5.3. The capacity of the CPI is big enough to produce the total required number of beer load carriers in week 7, so there is no need to perform pre-production, use the Manual CPIs or produce beer load carriers by hand.

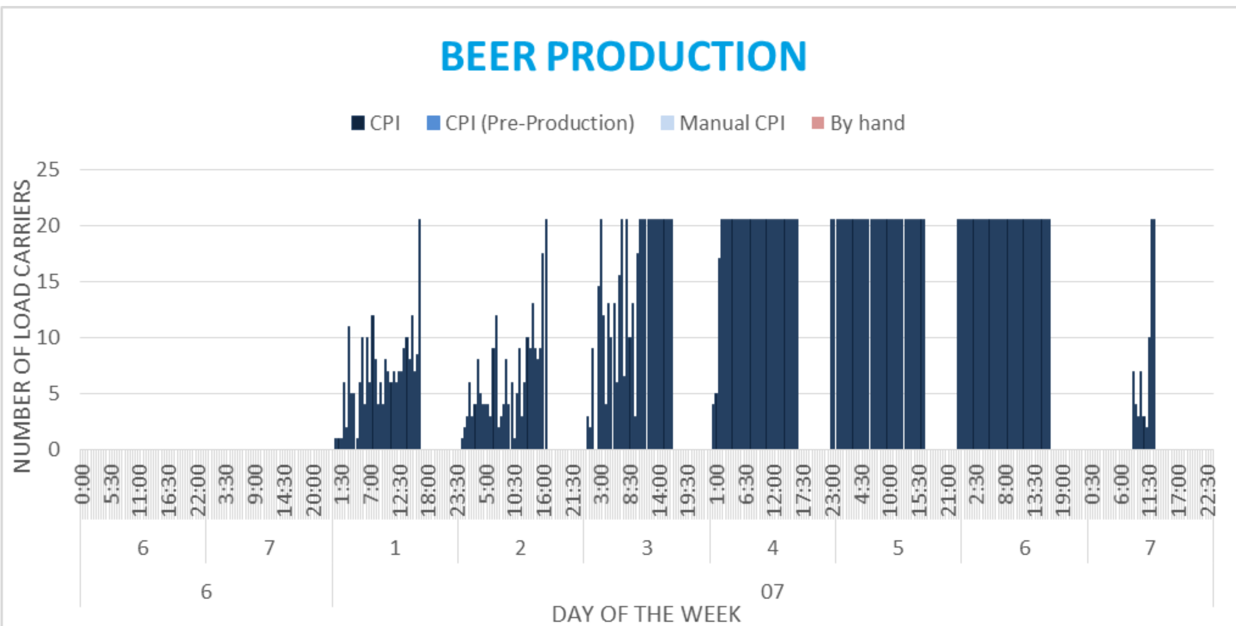


Figure 5.3 Beer production scenario 1

Using the output of both the general production and the beer production, we can determine the number of load carriers and the total size of the load carriers that are stored at the marshalling area at a certain timeslot. In Figure a graphical representation of the required size of the marshalling area is displayed.

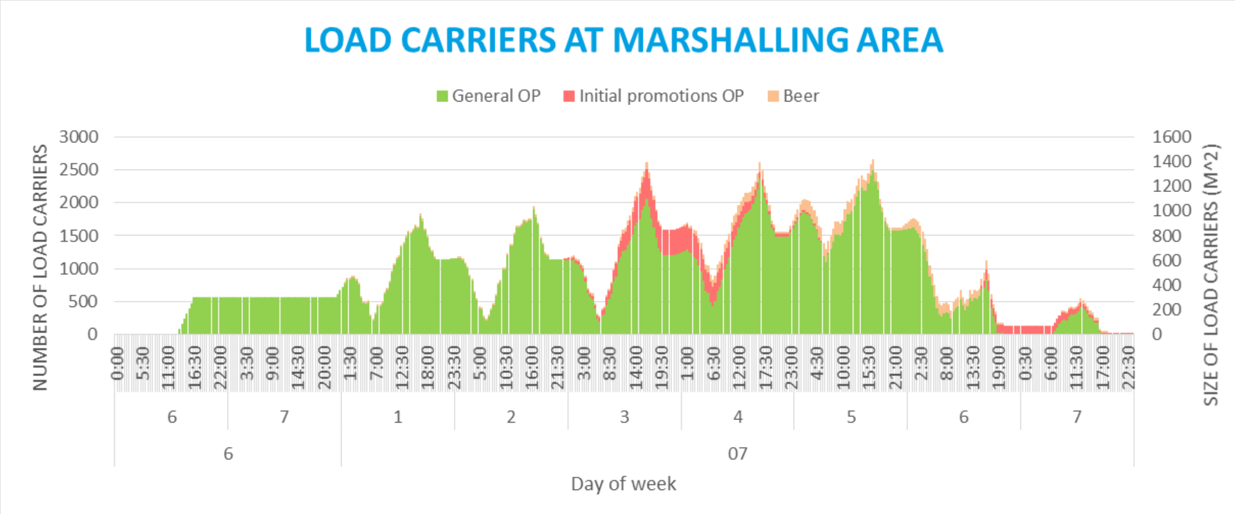


Figure 5.4 Load carriers at marshalling area scenario 1

The maximum number of load carriers that is present at the marshalling area at the same time in scenario 1 is 2,612. If we express this in the minimum required size of the marshalling area, we get a surface of 1,363 square meters. The total employee costs of order picking in scenario 1 equals 13,571.73 CUs, which is a decrease of nine per cent compared to the current situation. The standard deviation of the number of order pickers however is increased by 144 per cent to 39.51.

5.2.2 | Scenario 2: Production of initial promotions from Monday onwards (average week)

Settings

In this scenario we will set the start time of initial promotions at Sunday 11:00 p.m. This means that the production of initial promotions can start immediately in the new production week. We do not want to start the production of initial promotions earlier than this, since the shelves of the initial promotions aisles are still filled with promotional goods from the previous week. The rest of the settings will remain the same as in scenario 1. Also the beer production settings do not change, which means that the beer production is exactly the same as in scenario 1 and will not be discussed in this scenario.

Output

The production planning shows that the production of initial promotions is completely done at Monday, Tuesday and Wednesday. The production of initial promotions takes place at the beginning of the week, since the cheap production hours did not reach the maximum number of order pickers yet (95) when producing the regular orders. Producing initial promotions at the beginning of the week also results in a more evenly distributed production planning compared to scenario 1.

The output of this scenario shows a maximum number of load carriers at the marshalling area of 3,152 load carriers and a surface of 1,648 square meters. This is an increase of 285 square meters compared to scenario 1. However, both the costs and the standard deviation decreased compared to scenario 1. The costs decreased even further, namely with ten per cent or 13,481.10 CUs compared to the current situation. The standard deviation also decreased compared to scenario 1 by three per cent. Compared to the current situation this is still an increase of 141 per cent.

5.2.3 | Scenario 3: Minimum number of order pickers (average week)

Settings

In this scenario we decrease the number of order pickers as much as possible to a situation where the number of order pickers at the same time in the production process is as low as possible. However, the maximum number of order pickers must still lead to a feasible solution. The rest of the settings are kept the same as the settings used in scenario 2.

Output

The minimum required number of order pickers to make sure all load carriers are produced on time is 55. We can conclude that minimizing the maximum number of order pickers at the same time in the production process results in an even more evenly distributed production planning. The beer production remains the same as in the previous scenarios and is not discussed again in this scenario.

If we look at the output and compare this with the previous scenario, we see a decrease in the required size of the marshalling area. The maximum number of load carriers at the marshalling area in this scenario is 3,075, with a total size of 1,607 square meters. This is a reduction of 41 square meters compared to scenario 2. If we take a look at the costs of the new production process, we see an increase compared to the current situation of two per cent. This can be explained by the fact that more production takes place in more expensive hours. On the other hand, the standard deviation of the number of order pickers decreased by 47 per cent compared to the current situation.

5.2.4 | Scenario 4: Minimum number of order pickers, daytime order picking (average week)

Settings

In this scenario we change the order picking hours to only day order picking. So, we set the order picking times from Monday till Sunday from 07:00 a.m. till 11:00 p.m. We then decrease the number of order pickers as much as possible, till a situation where the number of order pickers at the same time in the production process is as low as possible but still leads to a feasible solution. The rest of the settings are kept the same as the settings used in the previous scenario.

Output

The minimum required number of order pickers to make sure all load carriers are produced in time is 62. We can conclude that it is possible to produce only during day hours, which makes it possible to stop producing during the night. Since the available order pick hours are changed, the beer production differs also compared to the previous scenarios. The capacity of the CPI during the open order pick hours is still sufficient to produce all beer load carriers in time, thus there is no need to pre-produce any beer load carriers or use manual CPI or by hand production.

The maximum number of load carriers at the marshalling area in this scenario is 3,355 load carriers. This equals a total required surface of 1,748 square meters. The total costs decreased by three per cent compared to the current situation to 14,911.02 CUs. However, the standard deviation increased by 16 per cent.

5.2.5 | Scenario 5: Minimum number of order pickers, order picking 24/7 (average week)

Settings

In scenario 5, all hours are open for order picking except for the reserved slot for the maintenance on the IT systems from 11:00 p.m. on Saturday till Sunday 05:00 a.m. Again, we decrease the number of order pickers as much as possible. The other settings will remain the same as in scenario 2, 3 and 4.

Output

The minimum required number of order pickers, to make sure all load carriers are produced on time, is 41. We can conclude that the production planning is quite evenly distributed and that the number of order pickers in the order pick process is almost the same during the whole week. The production peak on Saturday is formed by the fact that the production of these load carriers cannot start earlier, due to the earliest production time of these load carriers and the fact that order picking on Saturday is less expensive than on Sunday. The beer production process also changed compared to the previous scenarios. Again, all beer load carriers can be produced using the CPI without pre-production, since the number of beer load carriers did not change and the available order pick hours increased.

In this scenario the maximum number of load carriers at the marshalling area is 3,286 and the corresponding minimum required size of the marshalling area is 1,713 square meters. The total costs increased by five per cent compared to the current situation to 15,670.96 CUs. While the standard deviation decreased by 37 per cent to 10.12 compared to the current situation.

5.2.6 | Scenario 6: Decrease of the average order pick time by one minute using the settings of scenario 3 (average week)

Settings

In this scenario we decrease the average order pick time by one minute to 54 minutes and 49 seconds. A marshalling area could lead to a decrease in the average order pick time, this is explained in Chapter 6. Since a decrease in the average order pick time will lead to a different production planning in each of the previous scenario, we will use the settings of scenario 3 to see what the effects are on the production planning if the average order pick time is decreased by one minute. Since the production time of beer load carriers does not change, we can use the beer production process of scenario 3.

Output

We can conclude that the production process got a little less evenly distributed than the created production planning in scenario 3. Which can be explained by the fact that the total needed number of order pickers over the whole production week is decreased due to an increase in the productivity per hour. This leads to less order pickers at more expensive timeslots, while the number of order pickers at the less expensive timeslots remains the same.

If we take a look at the number of load carriers that are placed at the same time on the marshalling, we can see a small decrease of 21 load carriers compared to the outcomes of scenario 3. In this scenario the maximum number of load carriers is 3,054. This equals a surface of 1,596 square meters. Both the total costs and the standard deviation of the number of order pickers improved compared to scenario 3. The total costs decreased by two per cent compared to the total costs of scenario 3, which means that the total costs of this scenario are almost the same as the costs of the current situation. The standard deviation of the number of order pickers is decreased by 44 per cent compared to the current situation.

5.2.7 | Scenario 7: Maximum number of order pickers (maximum week)

Settings

In this scenario we change the average week to the maximum week (week 51). All other settings will remain the same as in scenario 1. This means that the current order pick hours will remain the same and the initial promotions load carriers are picked from Wednesday onwards. We use the maximum number of order pickers allowed at the same time in the order picking process, namely 95. Pre-production of beer load carriers is possible from Sunday 23:00 p.m. onwards.

Output

If we look at the output of this scenario, we see a production process that is not as evenly distributed as the current situation. The number of order pickers during the day is much higher than the number of order pickers during the night. There is no production on Sunday due to Christmas.

The beer production process changed in comparison to the average week, since the number of needed beer load carriers increased. The capacity of the CPI is not enough to produce all beer load carriers during the available order pick hours. This results in the pre-production that can be seen on Monday and Tuesday. However, even using pre-production on the CPI, the number of produced beer load carriers is still not enough to produce the necessary number of beer load carriers. That is why the manual CPI is used on Friday and Saturday.

The maximum number of load carriers that is present at the marshalling area at the same time in scenario 7 is 3,598. If we express this in the required size of the marshalling area, we get a surface of 1,880 square meters. The total employee costs of order picking in scenario 1 equals 16,073.07 CUs, which is a decrease of six per cent compared to the current situation. The standard deviation of the number of order pickers however is increased by 107 per cent to 34.37.

5.2.8 | Scenario 8: Maximum number of order pickers, initial promotions from Monday onwards (maximum week)

Settings

This scenario uses the same settings as scenario 7, however the start time of initial promotions is set at Sunday 11:00 p.m. instead of Wednesday.

Output

If we compare this scenario to the previous scenario we can see that the picking of initial promotions moved a little forward to the beginning of the week. In this scenario the initial promotion is picked partly on Monday and Tuesday. This results in a production planning that is slightly more evenly distributed.

From the newly created production planning we can conclude that the maximum number of load carriers at the marshalling area is 3,791 and that the corresponding minimum required size of the marshalling area is 1,983 square meters. The total costs decreased by six per cent compared to the current situation to 16,064.10 CUs. While the standard deviation increased by 106 per cent to 34.31 compared to the current situation.

5.2.9 | Scenario 9: Minimum number of order pickers, initial promotions from Monday onwards (maximum week)

Settings

In Scenario 9 we decrease the number of order pickers as much as possible to a situation where the number of order pickers at the same time in the production process is as low as possible. The production planning still has to lead to a feasible situation. The rest of the settings are kept the same as the settings used in scenario 8.

Output

If we look at the created production planning, we can see a quite evenly distributed production process. The minimum required number of order pickers in the order picking process at the same time that leads to a feasible solution is 68 and the initial promotions are picked from Monday till Thursday. Since we did not change any settings regarding the beer production, the beer production process will remain the same as in scenario 7 and 8.

If we look at the effects on the size of the marshalling area, we can see that the maximum number of load carriers put on the marshalling area is 3,618 and the required minimum surface corresponding to that number is 1,893 square meters. The total costs of order picking increased by one per cent compared to the current situation, while the standard deviation decreased by twenty per cent.

5.2.10 | Scenario 10: Lowest required size of the marshalling area (maximum week)

Settings

In this scenario we are decreasing the maximum number of order pickers in the process from 95 until the production process is not feasible anymore. We search for the lowest required size of the marshalling area. All other settings are kept the same as in Scenario 7. This means we will produce the initial promotions load carriers from Wednesday onwards.

Output

We reach the lowest required marshalling area, when the maximum number of order pickers in the order picking process at the same time is 85. Since we did not change any settings regarding the beer production, the beer production process will remain the same as in the previous scenarios of the maximum week.

If we look at the effects on the size of the marshalling area, we can see that the maximum number of load carriers put on the marshalling area is 3,386 and the required minimum surface corresponding to that number is 1,770 square meters. The total costs of order picking decreased by four per cent compared to the current situation, while the standard deviation decreased by 63 per cent.

5.3 | Summary of results

In this section we give an overview of the outcomes of all scenarios discussed in the previous section. To give an idea of the scale of the marshalling area, the size is compared to the number of staging lanes that it would cover. The used size of a staging lane is 31.2 square meters, which is the most common size of a staging lane at DCO. The number of staging lanes reserved for outbound transport at the same time in the current process is 46. Table 5.1 shows an overview of the outcomes of the scenarios for the average week. An overview of the scenarios for the maximum week are shown in Table 5.2. The outcomes of the case study are discussed in Section 6.1.

	Scenario 0 (Avg.)	**Scenario 1**	**Scenario 2**	**Scenario 3**
Week	Average	Average	Average	Average
Order pick hours	Current	Current	Current	Current
Max # order pickers	NA	95	95	Minimum (55)
Average pick duration	55:49	55:49	55:49	55:49
Start picking initial promotion	Wednesday	Wednesday	Monday	Monday
Total costs of order pickers	14,911.02 CUs	▼9 per cent	▼10 per cent	▲2 per cent
Standard deviation of # of order pickers	16.19	▲144 per cent	▲141 per cent	▼47 per cent
Required size of marshalling area in m^2	NA	1,363	1,648	1,607
# Staging lanes	46	43.69	52.82	51.51

	Scenario 4	**Scenario 5**	**Scenario 6**
Week	Average	Average	Average
Order pick hours	Only daytime	24/7	Current
Max # order pickers	Minimum (62)	Minimum (41)	55
Average pick duration	55:49	55:49	54:49 (decreased by one minute)
Start picking initial promotion	Monday	Monday	Monday
Total costs of order pickers	▼3 per cent	▲5 per cent	▬ 0 per cent
Standard deviation of # of order pickers	▲16 per cent	▼37 per cent	▼44 per cent
Required size of marshalling area in m^2	1,748	1,713	1,596
# Staging lanes	56.03	54.90	51.15

Table 5.1 Outcomes scenarios average week

	Scenario 0 (Max.)	**Scenario 7**	**Scenario 8**	**Scenario 9**	**Scenario 10**
Week	Maximum	Maximum	Maximum	Maximum	Maximum
Order pick hours	Current	Current	Current	Current	Current
Max # order pickers	NA	95	95	Minimum (68)	85
Average pick duration	55:49	55:49	55:49	55:49	55:49
Start picking initial promotion	Wednesday	Wednesday	Monday	Monday	Wednesday
Total costs of order pickers	17,107.21	▼6 per cent	▼6 per cent	▲1 per cent	▼4 per cent
Standard deviation of # of order pickers	16.63	▲107 per cent	▲106 per cent	▼20 per cent	▲63 per cent
Required size of marshalling area in m^2	NA	1,880	1,983	1,893	1,770
# Staging lanes	46	60.26	63.56	60.67	56.73

Table 5.2 Outcomes scenarios maximum week

6 | Discussion

The objective of this research is to investigate the effects of decoupling the production process and the dropping of load carriers using a marshalling area and to determine the required size of this area. In Section 6.1 the outcomes of the scenarios executed for DCO are discussed. Followed by the potential additional benefits a marshalling area in Section 6.2. There are some topics that need to be considered when implementing a marshalling area, these are described in Section 6.3. We think we made a good start by showing the effects of a marshalling area and the required size of a marshalling area, however there are some limitations to the results of this research. Those limitations are discussed in Section 6.4.

6.1 | Outcomes case study DCO

The required size of the marshalling area for produced load carriers (outbound flow) in the average week at DCO given the created scenarios varies from 1,363 square meters (scenario 1) to 1,748 square meters (scenario 4). The required size of the marshalling area for produced load carriers (outbound flow) in the maximum week at DCO given the created scenarios varies from 1,770 square meters (scenario 10) to 1,983 square meters (scenario 8). This means that the lowest required size of the marshalling of all performed scenarios using the maximum week exceeds the required size of the marshalling area of all the scenarios performed using the average week.

If we compare the lowest required size using the maximum week with the size of the current staging lanes reserved for outbound flows, we can see that the reserved space would increase by 23 per cent. Since we do not take into account the transito flow and the dollies/displays flow, we still have to reserve additional space for these flows. In the current situation these flows are, namely, all put on the reserved 46 outbound staging lanes. This means that the total area needed to process all outbound flows would be greater than 1,770 square meters.

A marshalling area makes it possible to schedule the production of initial promotions load carriers earlier in the week to increase the production in the beginning of the week and decrease the production in the end of the week. This results in a more evenly spread production planning and more production in cheaper timeslots. However, changing the start time of picking initial promotions from Wednesday to Monday increases the required size of the marshalling area quite a lot, as can be seen when comparing scenario 1 with scenario 2 and comparing scenario 7 and scenario 8.

From the outcomes we can conclude that a more evenly distributed production planning results in higher order picking costs compared to a situation where more order pickers are allowed to perform order picking at the same time. This can be concluded when comparing scenario 2 with scenario 3 and comparing scenario 8 with scenario 9. In these comparisons all settings are the same, except for the maximum number of order pickers in the order picking process at the same time. In scenario 3 and scenario 9 the number of order pickers is minimized, while in scenario 2 and 8 the maximum number of order pickers (95) is used. Decreasing the maximum number of order pickers in the order picking process at the same time, results in more production in more expensive timeslots. This results in higher total order picking costs. We can concluded from the outcomes that it is possible to decrease the total employee costs of order picking (scenario 1, 2, 3, 7, 8 and 10) by the implementation of a marshalling area.

However, on the other hand a more evenly distributed production planning results in a lower standard deviation of order pickers in the order picking process compared to a situation where more order pickers are allowed to perform order picking at the same time. This can also be concluded when comparing scenario 2 and scenario 3 with each other and comparing scenario 8 and scenario 9 with each other. This can be explained by the fact that the variation in the number of order pickers over de production week will decrease and thus the standard deviation of the number of order pickers will decrease. We can concluded from the outcomes that it is possible to decrease the standard deviation of the number of order pickers (scenario 3, 5, 6 and 9) by the implementation of a marshalling area.

If we would implement a marshalling area at DCO with the lowest required size in the maximum week, we make sure we are able to handle the produced load carriers in the maximum week and have enough space in the marshalling area to create a more desirable production process in the other weeks. This would increase the flexibility of the production process for all weeks that will not use the total surface of the marshalling area. The production process can easily be upscaled when it is needed. Even if the productivity during the shift is higher than predicted, it is possible to continue the order picking process and there is no need to stop order picking due to too less capacity at the marshalling area.

Implementing a marshalling area that has the lowest required size of the marshalling area at DCO in the maximum week makes it possible to perform only daytime order picking with the lowest number of order pickers in the order picking process at the same time, namely 62 order pickers. This could solve the problem of the ageing employees at Albert Heijn. It also leads to a decrease of three per cent in the total order picking costs compared to the current situation. However, it does lead to an increase of the standard deviation of the number of order pickers, namely 16 per cent.

6.2 | Potential additional benefits

We expect that a marshalling area will have some additional benefits. These potential addition benefits can be distinguished into two groups, the potential benefits for the DCs and the potential benefits for the stores. The provided potential benefits provided in this section are based on predictions and should be researched to determine if they really occur and in what degree.

6.2.1 | DCs

Increase in productivity

A more evenly distributed production planning means less order pickers in the system at the same time, which can result in less congestion within the order picking process. Another result of a more evenly distributed production planning could be that the restocking of goods from the buffers to the picking slots is also more spread during the day, due to a decrease in the overall number of picked goods per hour. This could also have a positive effect on the congestion created by forklifts in the order picking lanes. Less congestion can result in a more efficient order picking process and thus an increase in productivity.

If the number of different load carriers produced during a certain timeframe can be increased, more possible combinations of load carriers picked by one order picker are possible. If the Pick Order Build algorithm can deal with more load carriers, more efficient combinations of load carriers can be made. If the load carriers within an order are more similar to each other, the number of different products that needs to be picked in an order can be decreased. This could result in less stops and thus a possible decrease in the average order picking time.

Another decrease in the average order picking time could be achieved by removing the current process of the dropping of load carriers at the different staging lanes. If a marshalling area is implemented, an order picker has to drop the picked load carriers at the marshalling area instead of the staging lanes. If these dropping points can lead to a decrease in driving distance, for example by the fact that load carriers could be dropped at the marshalling area at only a few strategic places, the average order picking time could be decreased.

An increase in productivity and thus a decrease in the average order pick time could lead to a decrease in the total order picking costs. A one minute decrease of the average order pick time can already lead to a big decrease in the total order picking costs as shown in the case study performed at DCO. A one minute decrease in the average order pick time can already lead to a cost reduction of the total order picking costs of two percent, shown in scenario 6.

More efficient use of space

Since the production of load carriers that can be produced is not limited to the number of available staging lanes anymore, production can take place more flexible. In the current situation, a staging lane is used for one single trip. This means that the load carriers of an order cannot be produced, before we know that the reserved staging lane is empty when those load carriers are dropped. This results in an inefficient use of the total space reserved for outbound trips. A marshalling area could result in a more efficient use of available space, especially when the marshalling area could be built on a different level or multiple levels and thus uses vertical space that is empty in the current layout of the DC.

Better use of capacity of automated systems

Since the production of load carriers is not limited to the available staging lanes anymore, the number of load carriers that can be produced at a certain time window is more flexible. This would mean that the Triple-O could be used any hour of the day at its full capacity if there are enough load carriers to produce. However, the flexibility of the production process is not the only obstacle for the production on the Triple-O. Since there are only 290 product candidates, not every load carrier can be produced on the Triple-O. If the aim is to use the full capacity of the Triple-O every hour of the day, the Triple-O should be able to handle more types of goods.

Right now the CPI can already be used to its full capacity if pre-production is performed. However, there is not a fixed storage area for the pre-produced beer load carriers. This could result in dangerous situations if load carriers are placed outside the outbound staging lanes. A marshalling area that takes into account the beer load carriers can make sure all load carriers will be in a designated storage area without causing any safety issues.

Safety

A marshalling area could lead to a safer workplace. Since load carriers do not have to be placed outside the staging lanes or at the main road in case of *dubbelloop*, but are placed inside the marshalling area, unsafe situations can be avoided. However, this means that the size of the marshalling area should be big enough to handle all the load carriers produced.

If the marshalling area is also (partly) automated, the physical effort of moving load carriers around the staging lanes by employees of Albert Heijn could be reduced. This could reduce the number of employees with physical health problems due to repeatedly moving heavy load carriers.

Ready for future grow

A marshalling area could lead to a situation in which the DCs are able to handle future growth. In the current situation the production during a certain timeframe is limited to the number of staging lanes. A staging lane is reserved for one trip at the same time and is reserve for that trip from the moment the staging lane is available until the time the truck is loaded. That means a dock can only be used for the trips scheduled on the staging lanes next to that dock. In case of a marshalling area a dock is only reserved for the time that the actual loading takes place. This could mean that more trips can be loaded from a dock during a certain timeframe.

Order of loading

A marshalling area could make it possible to change the sequence in which the load carriers arrive at the truck for loading. Thus, the order of loading could be adapted to the wishes of the truck driver. This could also save time, since sorting the load carriers at the staging lanes while loading the truck could be eliminated.

Less impact in case of delays

If a truck is delayed in the current situation, the staging lane reserved for that trip will not be emptied at the predicted loading time. This could lead to *dubbelloop* if the load carriers of the next trip scheduled at that staging lane are already dropped, while the load carriers of the delayed truck are still there. A marshalling area could reduce the impact of a delayed truck, since the marshalling area could be able to provide the needed load carriers just before the truck arrives at the DC.

6.2.2 | Stores

Store delivery

Since the current production is based on the maximum number of trips that can be handled at the same time at the staging lanes of the DCs, the delivery schedule is based on the maximum capacity of the staging lanes. If the number of staging lanes is not a bottleneck anymore, the maximum number of trucks loaded within a certain timeslot could be increased and would be limited to the number of docks or the size of the marshalling area instead. If the number of trips that is produced at the same time can be increased and there are more docks available within a certain time window for loading, the number of trips that can depart within a certain time window could be increased. This could mean that more stores can be delivered at their desired delivery time.

Initial promotions

Next to the possibility of moving the production of initial promotions from the end of the week to the beginning of the week, it could also be possible to deliver the load carriers with initial promotions even later to the stores. If the marshalling area is big enough, load carriers with initial promotions could be stored in the marshalling area at the DCs instead of the back of the stores. This would result in more space at the storage of the stores. However, to do this the trucks at the end of the week should also be able to handle more initial promotions load carriers next to the other load carriers.

Order of loading

As discussed before, a marshalling area could make it possible to change the sequence in which the load carriers arrive at the truck for loading. Thus, the order of loading could be easily adapted to the wishes of the store.

6.3 | Implementation

The implementation of a marshalling area would mean a change in the current way of working. Load carriers are not dropped at the staging lanes anymore, but at the marshalling area. Also the process between dropping the load carriers and the actual loading of the truck will be changed. Since, a marshalling area could lead to a change in the current production planning, employees could be asked to work at other times and doing different tasks then their used to do. This could involve some resistance of the employees working at the DCs of Albert Heijn.

Besides a change in the way of working, a whole area in the DC needs to be dedicated to the marshalling area. The actual layout and place of this area is not determined in this research. However, if we look at the outcomes of the case study performed at DCO, the required size of the marshalling area is quite big and would involve a big change in the current layout of the DC.

Before actually implementing a marshalling area, we discuss some topics that should be considered. Some of these topics would require further research, which is discussed in Section 7.3.

Investment costs

To create a marshalling area, an investment is needed. The size of the needed investment highly depends on the layout and type (manual or (parly) automated and the used systems) of marshalling area. A manual marshalling area without any need for large reconstruction of the current building will have less investment costs than a construction that is fully automated and needs a lot of redesign on the current layout of the building. However, a manual marshalling area would probably mean that more employees are required to work at the marshalling area. So, both the investment costs and the costs of using the marshalling area highly depend on the type and layout of the marshalling area that is constructed.

The degree in which the marshalling area could be automated, highly depends on the current available technology that can be used in the marshalling area. Further research should be conducted on this topic to investigate the different options that are available now and are expected to be available in the near future. A marshalling area could also lead to the need for new software. Since load carriers of different trips could be combined into one storage area, the exact place of each load carrier needs to be known. Especially when the process is automated, the system has to know which load carriers belong to which trip and when they have to be at the dock for loading.

Change in the way of working

A marshalling area could lead to extra handling of the load carriers within the marshalling area, since load carriers have to be transported within the marshalling area. Not only extra handling between employees can take place, but also between employees and machines. This depends on the type of marshalling area that is used. This additional handling could also lead to an increase in the time between the moment the load carrier is dropped at the marshalling area and the time the load carrier is ready to be loaded.

A marshalling area means that employees have to be trained to be able to work with the new situation. It depends on the type of marshalling area, how much training the employees need. If the marshalling area will be (partly) manual, the training of employees will probably take more time than the training in case of an automated marshalling area. Also the current way of loading a truck could be changed if a marshalling area is used. The training of employees means an investment in time, which results in an increase in costs. To successfully implement the marshalling area and create acceptance among the employees, we have to show the employees that they would benefit from the new way of working.

Impact on other departments

A change in the current production process will have a big impact on, for example, the current replenishment of the goods. A change in the production process leads to goods needed at different times to replenish the stocks. This means that the replenishment department should also be included in decision making process before implementing the marshalling area. Another department that should be included in the decision making process is the transport department. A marshalling area could have an effect on the number of trips that can be loaded during a certain timeframe. Good communication between the different parties is key to make sure the marshalling area will have the desired impact on the current process.

6.4 | Research limitations

A limitation to our research is that the outcomes of the framework are based on both predicted and historical data. The outcomes would be more reliable if all the data used in the framework where based on historical data of 2016. Next to that, the framework uses averages to predict the production planning, which could also influence the outcomes of the framework.

An optimization model is not executed, this means we do not have hard prove that the created algorithms give us the optimal production planning that minimizes the employee costs of order picking and levels the production process as much as possible.

Another limitation to the outcomes of the framework is that future possible events like growth in the number of produced load carriers at the DCs or the influence of the new fully automated warehouse at Zaandam is not taken into account. The fully automated warehouse in Zaandam could take over some of the production that is done at DCO now, which can result in a smaller required size of the marshalling area.

7 | Conclusion

In this chapter we describe our conclusion in Section 7.1, followed by our recommendations in Section 7.2. We end this chapter with some topics that are interesting for future research in Section 7.3.

7.1 | Conclusion

We have conducted a research to investigate the effects of decoupling the production process and the dropping of load carriers using a marshalling area and determined the required size of this area. The objective of this research is as follows:

"The current flexibility and planning of the production is limited to the capacity and the use of the staging lanes, which makes the production schedule fluctuating and costly. There is a need for a framework that shows the effects of decoupling the production process and the dropping of the load carriers at the staging lanes using a marshalling area and determines the required size of this area."

To investigate the effects of a marshalling area on the production planning and costs of order picking, we created a general framework in Excel VBA. We used Excel to create this framework, since AH is familiar with Excel and can adapt the framework as wished. The created framework can be used for each of the DCs of AH. To validate the framework we perform different scenarios at DCO. Each of these scenarios is performed using data from the average and maximum week of 2016. The scenarios showed that a marshalling area has a big influence on the order picking process. While, the distribution of the order pickers over de production week has a big influence on the costs of order picking, the standard deviation of order pickers in the production planning and the required size of the marshalling area. From the case study performed at DCO we can conclude the following:

- Implementing a marshalling area at DCO with the lowest required size in the maximum week (1,770) makes sure that the produced load carriers in the maximum week can be handled by the marshalling area and it gives the possibility to create a more desirable production process in the other weeks of the year.
- Picking of initial promotions load carriers in the beginning of the week leads to a more evenly distributed production planning, but results in a higher required size of the marshalling area.
- A marshalling area can lead to a decrease of the total costs of order pickers in the production process. However, a more evenly distributed production planning results in an increase in the total order pickings costs compared to a situation where more order pickers are allowed to perform order picking at the same time, keeping all other settings the same.

- A marshalling area can lead to a decrease of the standard deviation of the number of order pickers in the production process. A more evenly distributed production planning results in a decrease in the standard deviation of order pickers in the order picking process compared to a situation where more order pickers are allowed to perform order picking at the same time, keeping all other settings the same.
- A one minute decrease in average order pick time (55 minutes and 49 seconds) could already lead to a decrease in costs of two per cent compared to a scenario where all other settings are kept the same.

A marshalling area could also lead to the following additional benefits for the DCs and the stores when implemented.

Potential additional benefits for DCs	Potential additional benefits for stores
Increase in productivity of order pickers	More stores delivered at their desired delivery time
A more efficient use of space	Initial promotions stored at the DCs
Better use of capacity of automated systems	Order of loading can be determined by the store
A safer workplace	
Ready for future growth	
Less impact in case of delays	
Order of loading can be determined by the truck driver	

Table 7.1 Potential additional benefits when implementing a marshalling area

Before actually implementing a marshalling area, some topics should be considered. A marshalling area will require an investment, this investment highly depends on the size, type and layout of the marshalling area. Further, it will change the current way of working. To successfully implement the marshalling area, acceptance among employees is required and employees have to be able to work with the marshalling area. Lastly, a marshalling area will have an impact on other departments within the supply chain of AH. This means good communication between the departments is key to get the desired impact on the production process.

7.2 | Recommendation

Based on our research, we recommend AH to decouple the production process and the dropping of the load carriers. A marshalling area would be a good solution to the current existing problems regarding the use of the staging lanes and would result in a more flexible production process. Next to that, a marshalling area could lead to a decrease in the total order picking costs, a safer workplace and readiness for future growth. We recommend AH to use the created framework in this research to perform similar scenarios in the other DCs, to gain insight in the required size of the marshalling area at these DCs.

We recommend AH to invest in a marshalling area that has the minimum size required to be able to handle the number of produced load carriers during the maximum week. This would lead to a size that is large enough to be able to create a more desired production planning during other production weeks with less load carriers to produce. As shown in the case study at DCO, this would even mean that all the load carriers can be produced during daytime. This could solve the current ageing problem at AH.

However, before actually implementing a marshalling area we do recommend AH to perform some extensive additional research. Especially on the different types (manual, (partly) automated and the used systems) of marshalling areas, possible layouts and the current available technology that can be used in a marshalling area. Since this will have a big impact on the potential additional benefits and the implementation of the marshalling. Further we recommend AH to involve other departments that are influenced by a marshalling area and the employees in the DCs, since implementing a marshalling are will have a big influence on the current way of working.

7.3 | Further research

To get a clearer picture of the actual impact of a marshalling area, we suggest that the scope should be broadened. In this research only the outbound flow of load carriers that are picked within the warehouse is taken into account. This means that the current predicted required size of the marshalling area for each scenario stated in this research does not include the load carriers of the transito and the dollies/displays flow. Additional research should show if it is beneficial to include these flows in the marshalling area and what the required size of the marshalling area would be if these flows are included.

To be able to say more about the effects of reducing the number order pickers in the order picking process at the same time, the correlation between the number of order pickers in the order picking process and the efficiency of order picking should be researched. With this correlation, we can predict the new average pick duration and the influence of this new average pick duration on the production process and, in particular, the cost savings. The possible costs savings due to a decrease in the average pick duration can influence the choice of production settings used to predict the required size of the marshalling area.

In our research we used the average order pick time of all order pick areas to predict the minimum required size of the marshalling area. However, a research should be conducted about the effects on the required size of the marshalling area using the average order pick time per order pick area instead of the total average order pick time. Another distinction can be made between load carriers with a high order pick time and load carriers with a short order pick time. This could also result in a different required size of the marshalling area.

To determine the costs of a particular size of the marshalling area, a research should be conducted that shows the relationship between the size of the marshalling area and the costs of the marshalling area. If the relationship between those variables is known, the costs of the marshalling area could be compared to the costs savings of the production process and the benefits of the marshalling area.

Finally, the actual layout and type of the marshalling area should be researched. While this has a big impact on the potential additional benefits and the implementation of the marshalling area. A research on this topic should show what kind of technology is available that can be used for the marshalling area. An overview of the different options, the additional benefits of a particular option and the impact on implementation would give us a better insight in the layout and type of marshalling area that should be implemented.

References

Ahold. (2015). *Annual Report 2015*. Retrieved February 14, 2017, from https://www.aholddelhaize.com/media/1370/ahold_ar15_fullreport_interactive.pdf

Ahold Delhaize. (2017a). *Company overview*. Retrieved February 14, 2017, from https://www.aholddelhaize.com/en/about-us/company-overview/

Ahold Delhaize. (2017b). *Where we operate*. Retrieved February 14, 2017, from https://www.aholddelhaize.com/en/about-us/where-we-operate/

Ahold Delhaize. (2017c). *Netherlands*. Retrieved February 14, 2017, from https://www.aholddelhaize.com/en/brands/netherlands/

Albert Heijn. (2016). *Inlegvel bij de cao voor het personeel van Logistics bij Albert Heijn bv 2014-2015.* Retrieved September 06, 2017

Bartholdi III, J. J., & Gue, K. R. (2000). Reducing Labor Costs in an LTL Crossdocking Terminal. *Operations Research*, 823-832. Retrieved March 20, 2017

Boysen, N., Scholl, A., & Wopperer, N. (2012). Resequencing of mixed-model assembly lines: Survey and research agenda. *European Journal of Operational Research*, 594-604. Retrieved November 18, 2017

De Koster, R., Le-Duc, T., & Roodbergen, K. J. (2007). Design and control of warehouse order picking: A literature review. *European Journal of Operational Research*(182), 481-501. Retrieved March 2017, 2017

Dekker, R., de Koster, M. B., Roodbergen, K. J., & van Kalleveen, H. (2004). Improving Order-Picking Response Time at Ankor's Warehouse. *Interfaces, 34*(4), 303-313. Retrieved March 31, 2017

Gusikhin, O., Caprihan, R., & Stecke, K. E. (2008). Least in-sequence probability heuristic for mixed-volume production lines. *International Journal of Production Research*, 647-673. Retrieved November 12, 2017

Inman, R. R. (2003). ASRS sizing for recreating automotive assembly. *International Journal of Production Research*, 847-863. Retrieved November 12, 2017

IRI. (2017). *Albert Heijn dé winnaar en Discount dé verliezer van 2016*. Retrieved February 23, 2017, from https://www.iriworldwide.com/nl-NL/insights/pressreleases

Koster, R. d. (2004). *How to assess a warehouse operation in a single tour.* the Netherlands: RSM Erasmus University. Retrieved March 28, 2017

Tompkins, J. A., White, J. A., Bozer, Y. A., Frazelle, E. H., & Tanchoco, J. M. (2010). *Facilities Planning.* NJ: John Wiley & Sons. Retrieved March 28, 2017

van den Berg, J., & Zijm, W. (1999). Models for warehouse management: Classification and examples. *International Journal of Production Economics*, Vol. 59, 519-528. Retrieved March 20, 2017

Appendices

Appendix I – Example of trips

Trip 1974 is a delivery of two stores from DCT, namely a store in Beveren and Nijlen. The expected number of load carriers for the store in Beveren is 27 and for Nijlen 23, this means the total expected number of load carriers to be transferred is 50. The assigned truck to this trip has a capacity of 54. For this trip, staging lane 408a and 408b are reserved at dock 55. 408a for the store in Nijlen and 408b for the store in Beveren. The staging lane is released at 09:00 p.m. (ETS), which is only an administrative time and does not mean anything, since order picking does not start before 11:00 p.m. So load carriers are put on this staging lane from 11:00 p.m. onwards. The planned start of loading the truck is at 03:42 a.m., which means the LTS is 03:27 a.m. (fifteen minutes before loading). The truck should be loaded before 04:12 a.m., which means the total loading time is 30 minutes and the truck leaves at 04:32 a.m. The timeframe for delivery for the first store on the route (Beveren) is from 06:00 a.m. until 07:00 a.m., and the scheduled delivery time on this trip is 06:00 for this store. The second store has a delivery timeframe from 07:00 a.m. until 08:00 a.m. and is planned to be delivered at 07:38 a.m.

Trip 1349 is the next trip scheduled on staging lane 408 (a&b). This trip goes first to a store in Breda, with an expected number of 25 load carriers, and then to a store in Roosendaal, with an expected number of 29 load carriers. So the total number of expected load carriers is 54, and a truck with a capacity of 54 is assigned to this trip. The ETS of the staging lane is at 04:12 a.m., since the previous truck should be loaded by that time, so the staging lane should be empty. The LTS of the staging lane is 07:53 a.m. and is loaded at 08:08. At 08:40 a.m. the truck should be loaded, which means the total loading time cannot take more than 32 minutes. The timeframe for delivery for the store in Breda is from 09:30 a.m. until 10:30 a.m., and the scheduled delivery time on this trip is 09:30 a.m. for this store. The second store has a delivery timeframe from 10:00 a.m. until 11:00 a.m. and is planned to be delivered at 10:32 a.m.

Appendix II – Load carriers

Load carrier	Details	Picture
Roll cage	66 cm x 80 cm	
Rolly	60 cm x 80 cm	
Dolly	30 cm x 40 cm	
Display	30 cm x 40 cm	

Appendix III – Utilization staging lanes DCO average week

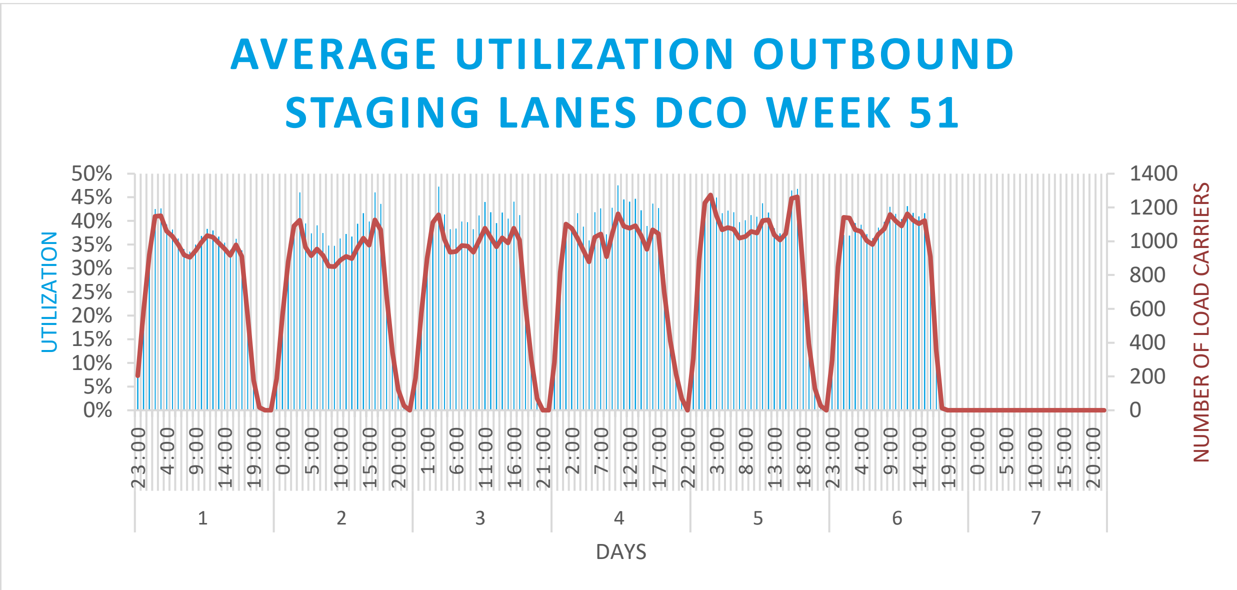


Figure III.1 Average utilization of the outbound staging lanes in the maximum week per hour

Appendix IV – Surcharge per hour

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0:00	55%	39%	39%	39%	39%	60%	100%
1:00	55%	39%	39%	39%	39%	60%	100%
2:00	55%	39%	39%	39%	39%	60%	100%
3:00	55%	39%	39%	39%	39%	60%	100%
4:00	55%	39%	39%	39%	39%	60%	100%
5:00	55%	39%	39%	39%	39%	60%	100%
6:00	55%	39%	39%	39%	39%	60%	100%
7:00	0%	0%	0%	0%	0%	35%	100%
8:00	0%	0%	0%	0%	0%	35%	100%
9:00	0%	0%	0%	0%	0%	35%	100%
10:00	0%	0%	0%	0%	0%	35%	100%
11:00	0%	0%	0%	0%	0%	35%	100%
12:00	0%	0%	0%	0%	0%	35%	100%
13:00	0%	0%	0%	0%	0%	35%	100%
14:00	0%	0%	0%	0%	0%	35%	100%
15:00	0%	0%	0%	0%	0%	35%	100%
16:00	0%	0%	0%	0%	0%	35%	100%
17:00	0%	0%	0%	0%	0%	35%	100%
18:00	37%	37%	37%	37%	55%	70%	100%
19:00	37%	37%	37%	37%	55%	70%	100%
20:00	37%	37%	37%	37%	55%	70%	55%
21:00	37%	37%	37%	37%	55%	70%	55%
22:00	37%	37%	37%	37%	55%	70%	55%
23:00	39%	39%	39%	39%	60%	70%	55%

Table IV.1 Surcharge of an order picker per hour per weekday

Appendix V – Input Screen

Parameters			
DC	DCO		
Week	07		
Area	Ambient		
Max orderpickers	56		
Area Percentage	100%		
Serviceperc.	100%		
Pick capacity	90%		
Current average Pick Duration (incl. dropping at staging lanes)	0:55:49		
New average Pick Duration (excl. dropping at staging lanes)	0:55:49		
Safety time	0:15	(15 minutes standard)	
Handling time at marshalling area	0:00		
Employees at marshalling area	0		
Time between OBM and possible release	1:30		
Start time initial promotions	23:00	Sunday	Week before
Pre-production possible?	Ja		
Pre-production possible from	23:00	Sunday	Week before
Maximum capacity in LC CPI per hour	41	(Standard: 41 LC)	
Maximum capacity at Manual CPI per hour	25	(Standard: 25 LC)	
Number of Manual CPI	2		
Remaining beer production by hand	Latest		
Maximal production of beer load carriers by hand per hour using latest production as	20		
Maximum capacity Triple-O per hour			

Sizes in m^2	
Roll cage	0,528
Rolly	0,48
Dolly	0,12
Display	0,12

Dashboard Direct Hours		
Zone	Colli	Percentage
Voice Pick Colli DCO	944.483	80,99%
Display DCO	166	0,01%
Dolly DCO	7.500	0,64%
KPI DCO	60.816	5,21%
Transito Colli Bloemen DCO	22.164	1,90%
Transito Colli Note DCO	118.358	10,15%
Transito Containers Bloemen DCC	2.333	0,20%
Transito Containers Note DCO	2.192	0,19%
Transito Containers LDC DCO	8.200	0,70%
Triple-O DCO	-	0,00%

Change order pick hours

Change order pick costs

Reset percentages

Density Dashboard							
Zone	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
h02 (dolly) DCO 07	1,88%	1,53%	1,13%	1,46%	3,20%	4,89%	4,84%
h03 (display) DCO 07	0,14%	0,50%	0,50%	0,66%	0,48%	0,83%	1,27%
h10 (fust) DCO 07	16,51%	13,71%	11,54%	13,15%	16,00%	16,14%	15,03%
h11 (621-644) DCO 07	27,39%	24,50%	21,06%	21,42%	23,35%	24,94%	25,22%
h12 (651-674) DCO 07	29,86%	25,41%	21,76%	22,21%	22,31%	24,80%	26,11%
h23 (returnings) DCO 07	8,89%	10,26%	9,88%	9,92%	9,25%	4,84%	3,06%
-	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
h31 (promotions) DCO 07	11,19%	19,65%	17,53%	15,93%	13,36%	8,10%	3,18%
h32 (initial promotions) DCO 07	0,00%	0,00%	7,60%	5,41%	1,82%	4,62%	12,74%
h90 (CPI) DCO 07	4,15%	4,44%	8,99%	9,84%	10,23%	10,84%	8,54%

Zone	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
-	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%
-	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

	1	2	3	4	5	6	7
Percentage Transito	13,14%	13,14%	13,14%	13,14%	13,14%	13,14%	13,14%
Percentage picked in DC	86,86%	86,86%	86,86%	86,86%	86,86%	86,86%	86,86%
Percentage dolly/display	1,75%	1,76%	1,42%	1,84%	3,20%	4,97%	5,31%
Percentage normal picks	81,51%	81,24%	71,02%	71,77%	73,20%	68,46%	63,06%
Percentage initial promotion	0,00%	0,00%	6,60%	4,70%	1,58%	4,01%	11,07%
Percentage CPI	3,60%	3,86%	7,81%	8,55%	8,89%	9,42%	7,42%
Percentage Triple-O	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%

Figure V.1 Input screen of framework in Excel

Appendix VI – Pseudo codes

Order picking general orders

For *t* = last timeslot (*L*) to *t* = first timeslot (*F*) do

If *t* has FinishNumLC > 0 then

For *i* = *L* to *i* =*F*

Find *i* for which the Total Production from *i* till L < the FinishNumLC from *i* till *L*

Initialize timeslot *s* with high costs and high number of order pickers

If production is not enough then

If total StartNumLC from *i* till *L* > Total Production from *i* till *L* then

If *i* is open AND the maximum capacity of order pickers at *i* has not been reached yet AND the costs of s ≥ costs of *i* AND the number of order pickers at *i* ≤ the number of order pickers at *s* then

Overwrite *s* by *i* AND set *i* = *i* – 1

Else set timeslot *i* = *i* - 1

End if

Else,

If *s* is not overwritten by any *i* then

Current settings lead to an infeasible solution AND algorithm stops

Else,

Add an order picker to *i* AND set *i* to *F*

End if

End if

Else, set timeslot *t* = *t* – 1

End if

Next *i*

Else, set *t* = *t* – 1

End if

Next *t*

Beer production

For *t* = last timeslot (*L)* to *t* = first timeslot (*F)* do

If *t* has FinishNumLC > 0 then

Set BeerNeeded = FinishNumLCs in *t*

Do while BeerProduced < BeerNeeded

If total StartNumLC from *i* till *L* > Total Production from *i* till *L* then

If *i* is open AND the maximum capacity at *i* has not been reached yet then

Add a beer load carrier to *i AND* set BeerProduced = BeerProduced + 1

Else,

Set *i* = *i* – 1

End if

Else, BeerRemaining in *t* = BeerNeeded – BeerProduced AND set BeerProduced = BeerNeeded

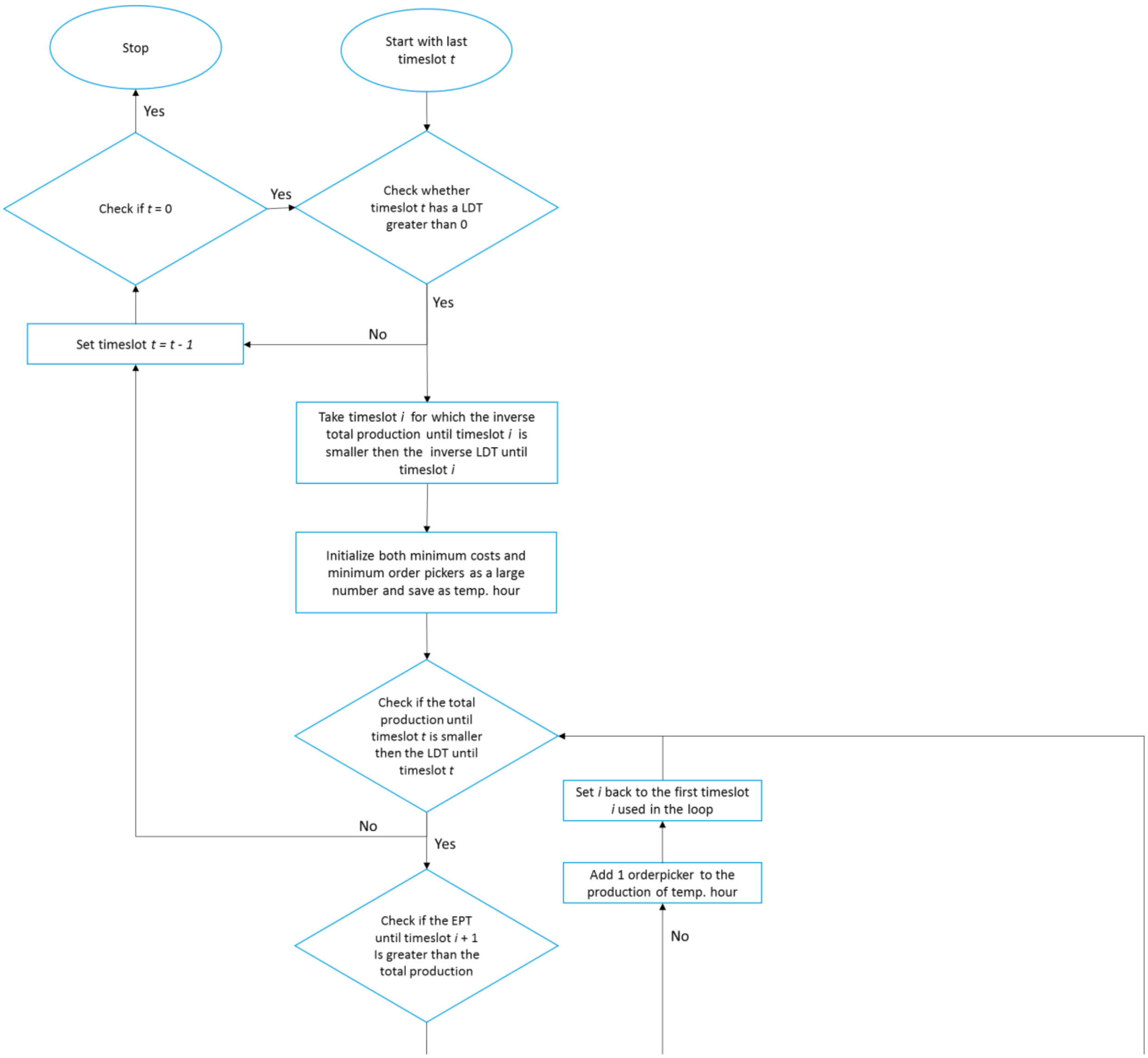
End if

Loop

End if

Next *t*

Appendix VII – Order picking general production process



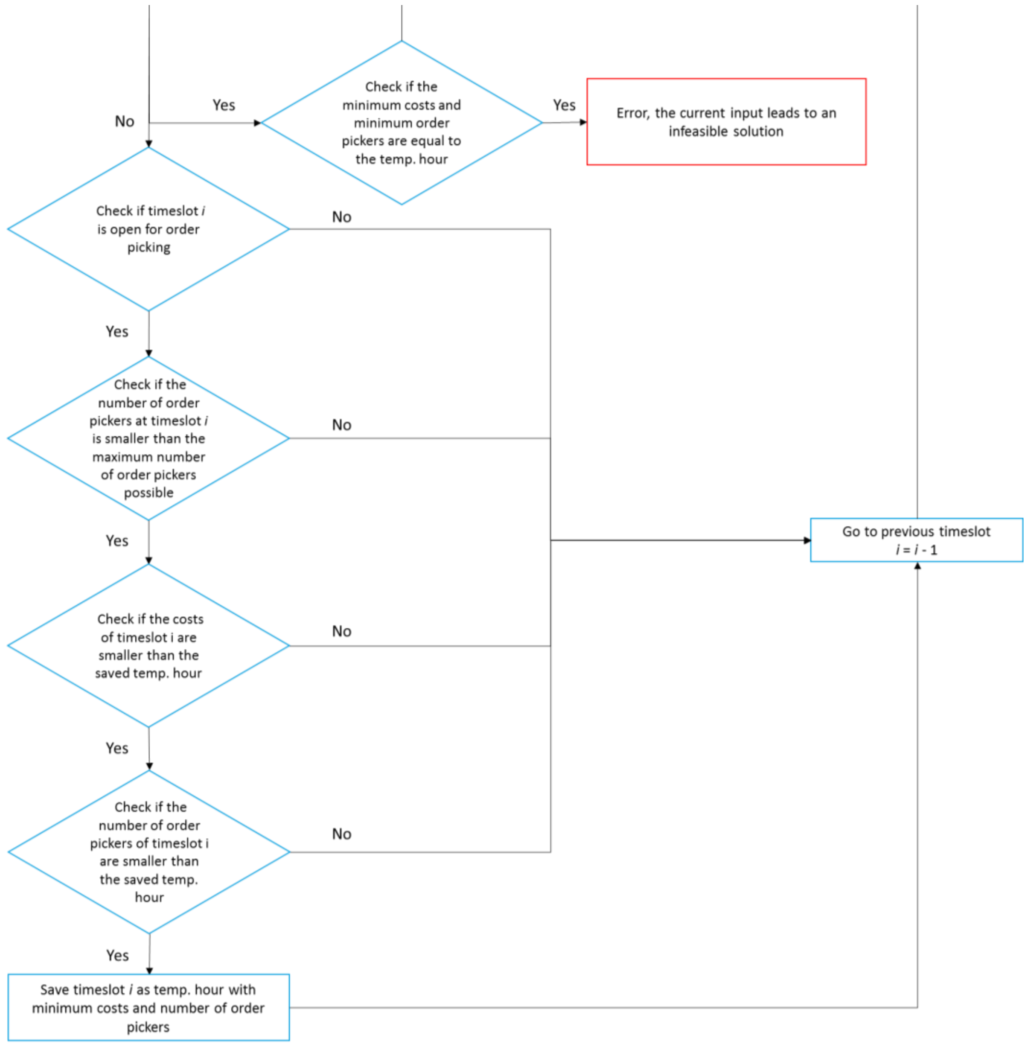


Figure VII.1 Flowchart of general orders production algorithm

Appendix VIII – Beer production process

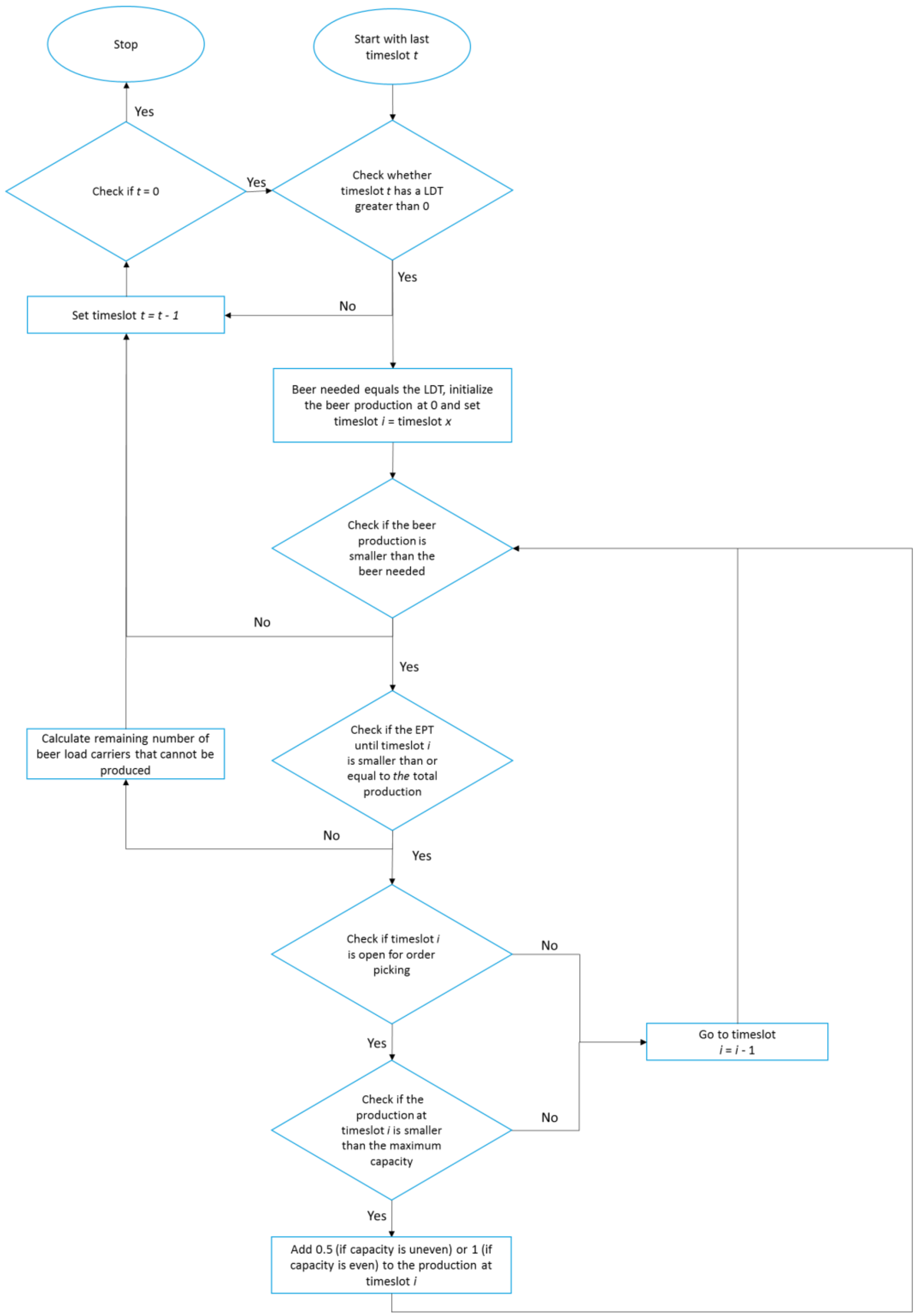


Figure VIII.1 Flowchart of beer production algorithm

Appendix IX – Output Screen

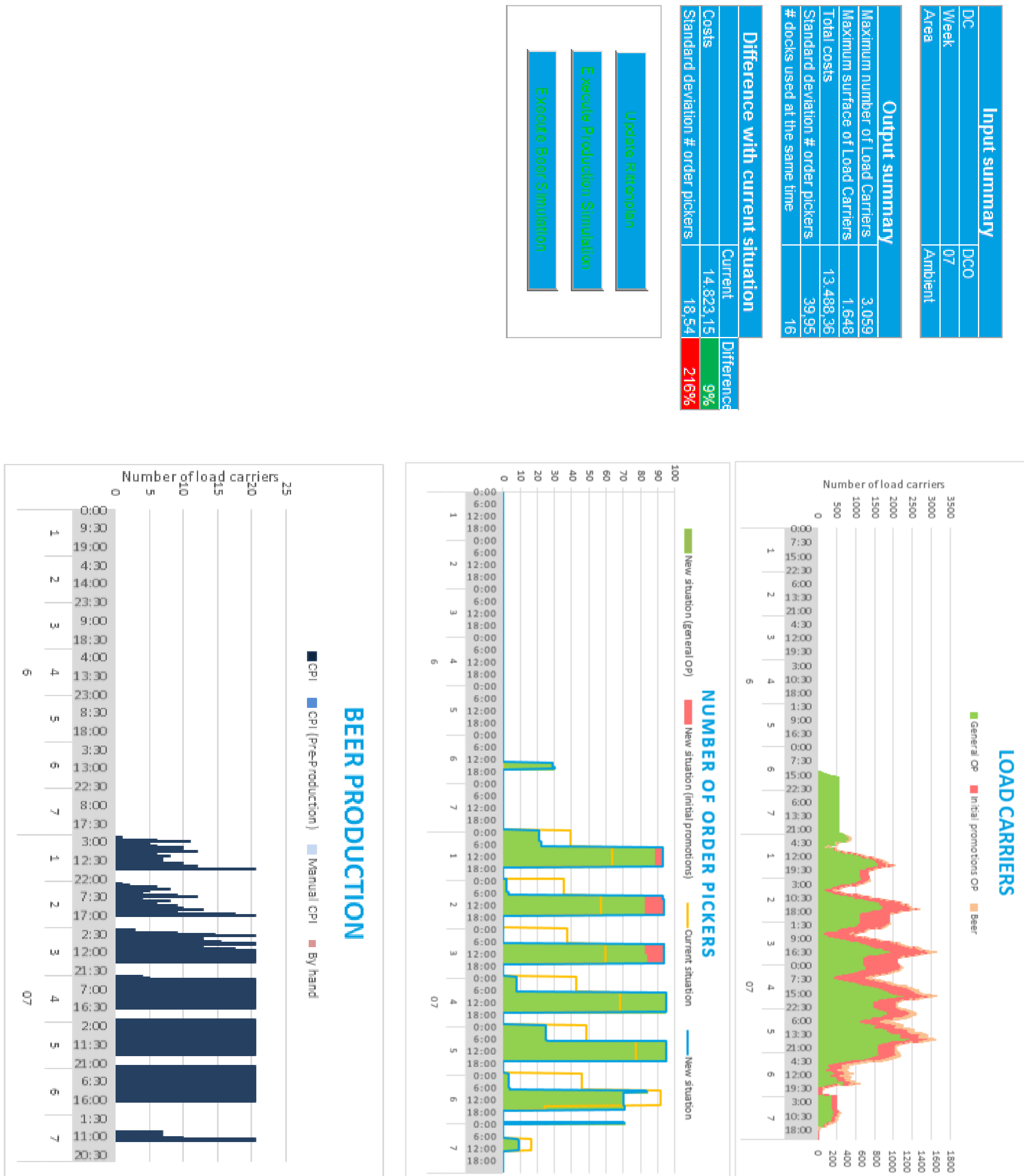


Figure IX.1 Output screen of framework in Excel

Appendix X – Average order pick time

No. Cars	LDC	DCO	DCP	DCT	DCZ
1	0:03:27	0:11:11	0:06:12	0:09:23	0:11:17
2	1:32:23	0:33:12	0:20:44	0:32:37	0:27:18
3	1:49:19	0:40:53	0:32:15	0:40:57	0:40:45
4	1:58:29	0:46:44	0:42:52	0:49:47	0:44:46
5	2:14:46	0:55:49	0:51:40	0:56:35	0:53:57

Table X.1 Average order pick time per number of cars picked at the same time per DC

Appendix XI – Graphs of scenarios

Scenario 2: Production of initial promotions from Monday onwards (average week)

Order picking general orders

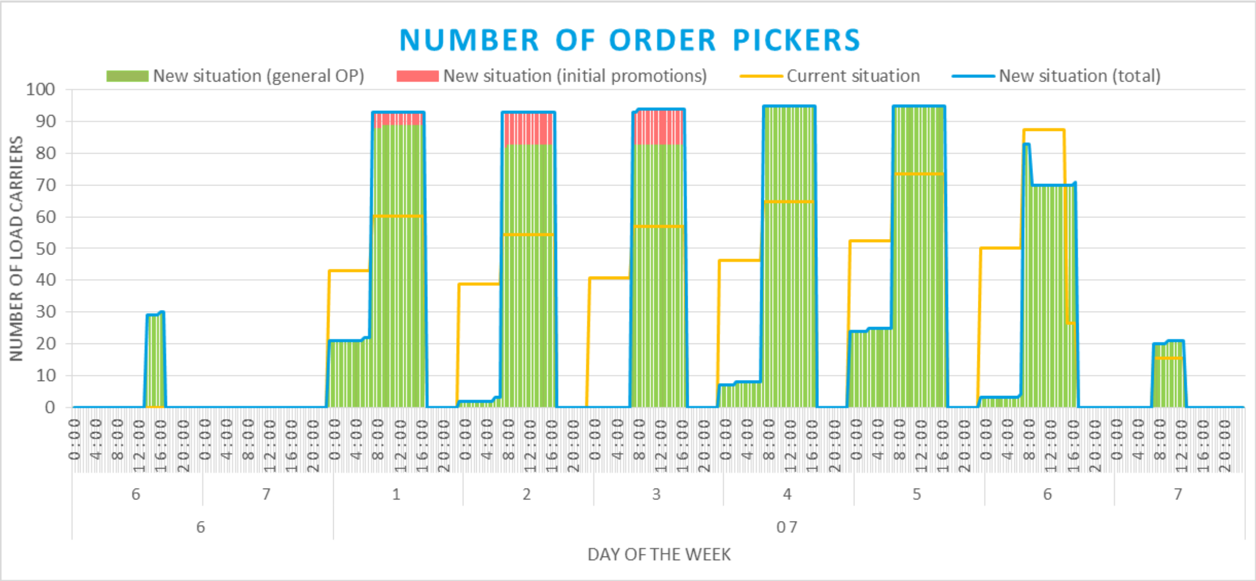


Figure XI.1 Production process scenario 2

Size marshalling area

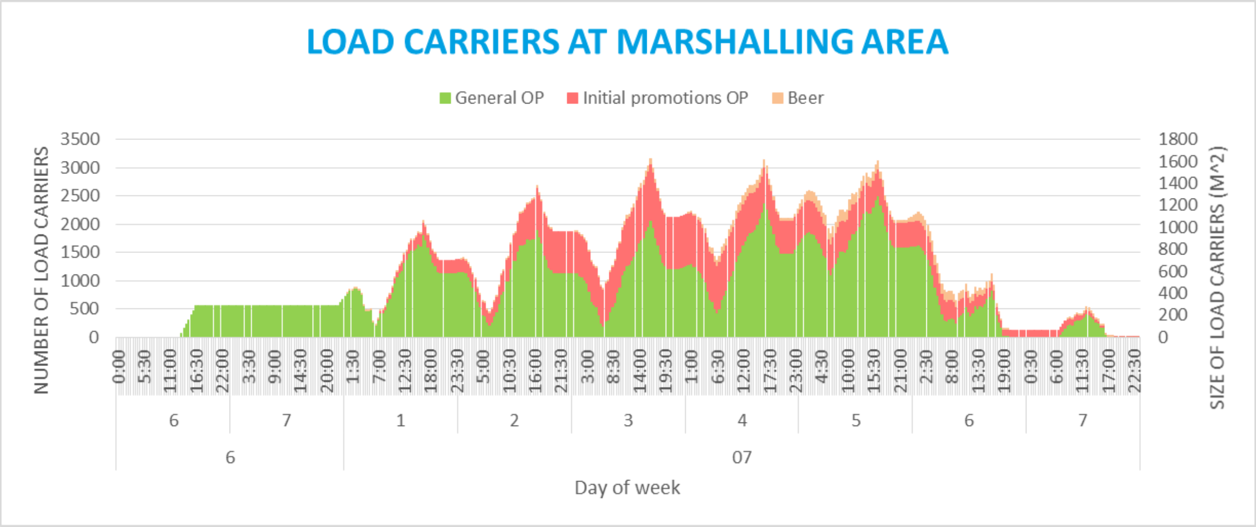


Figure XI.2 Load carriers at marshalling area scenario 2

Scenario 3: Minimum number of order pickers (average week)

Order picking general orders

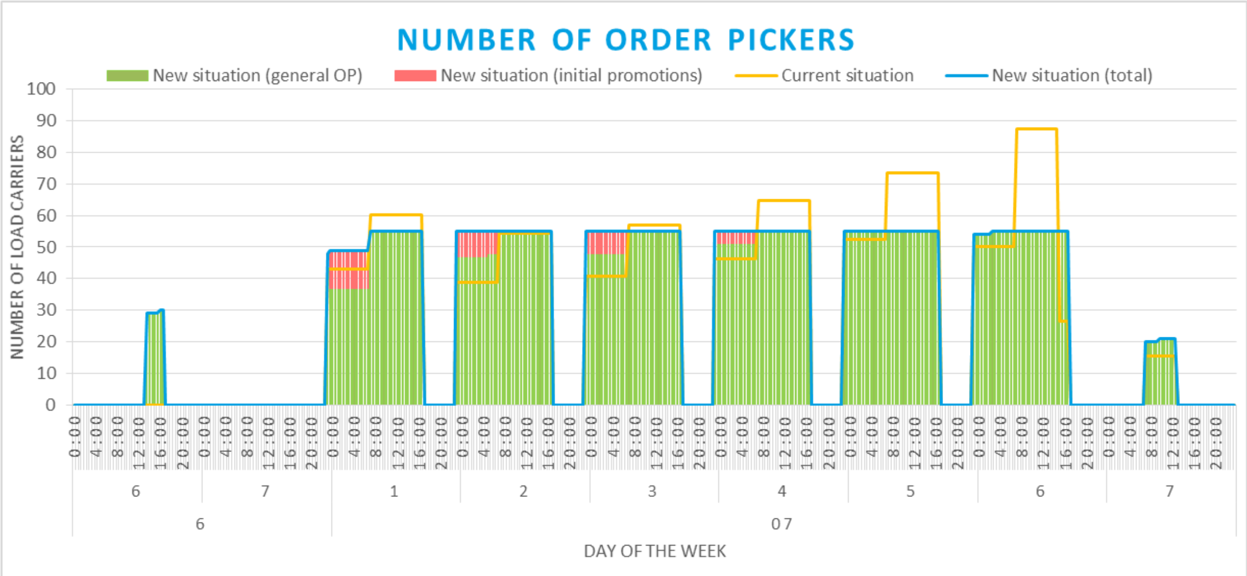


Figure XI.3 Production process scenario 3

Size marshalling area

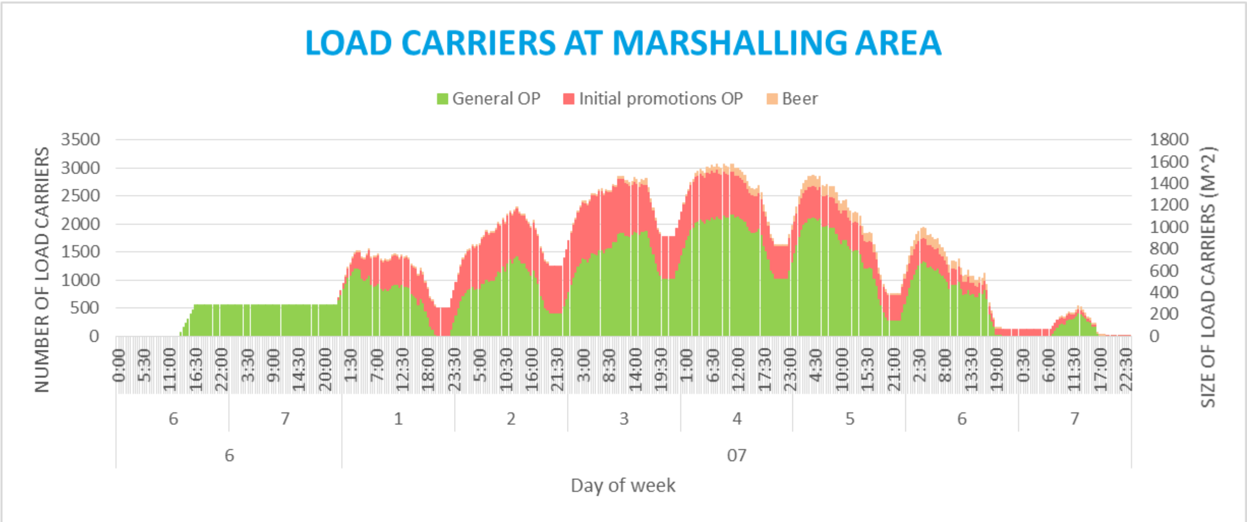


Figure XI.4 Load carriers at marshalling area scenario 3

Scenario 4: Minimum number of order pickers, daytime order picking (average week)

Order picking general orders

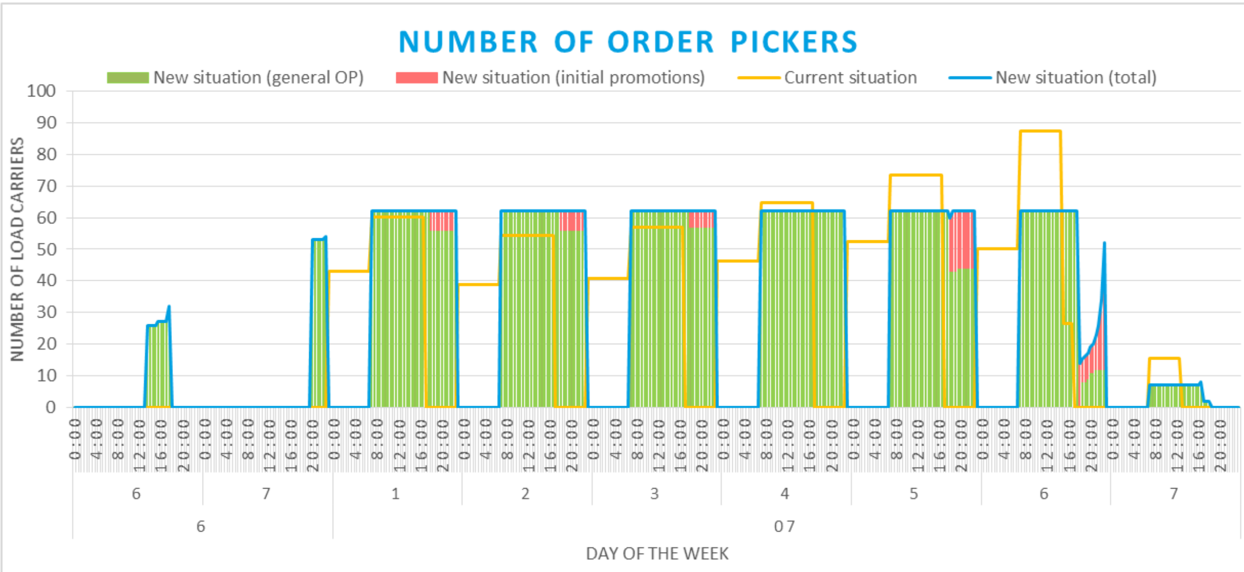


Figure XI.5 Production process scenario 4

Beer production

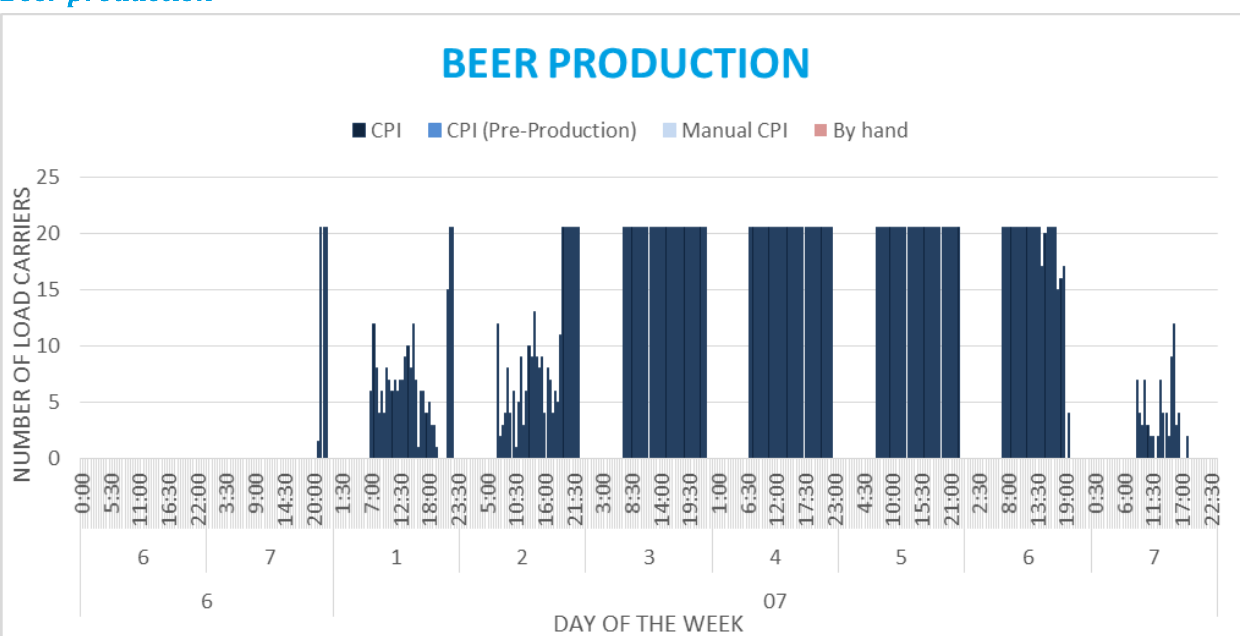


Figure XI.6 Beer production scenario 4

Size marshalling area

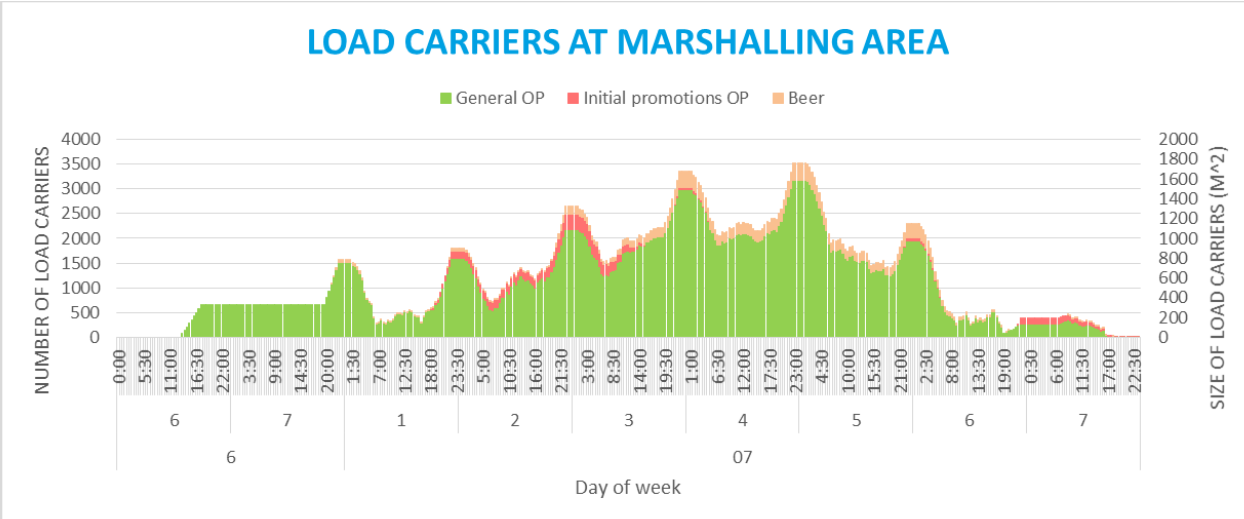


Figure XI.7 Load carriers at marshalling area scenario 4

Scenario 5: Minimum number of order pickers, order picking always possible (average week)

Order picking general orders

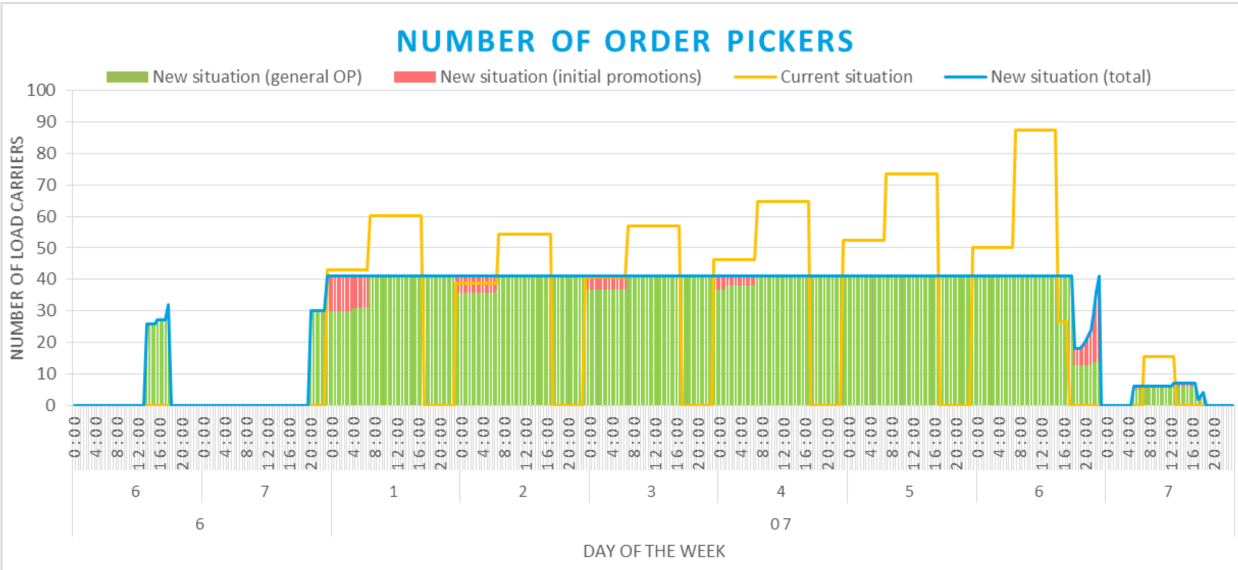


Figure XI.8 Production process scenario 5

Beer production

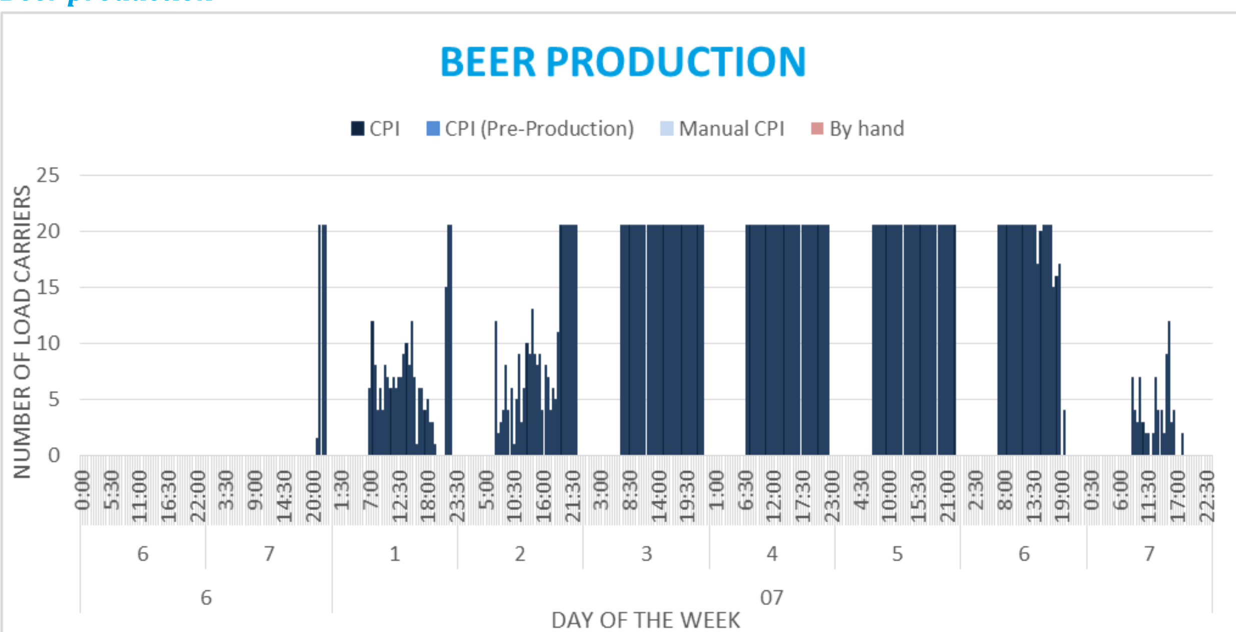


Figure XI.9 Beer production scenario 5

Size marshalling area

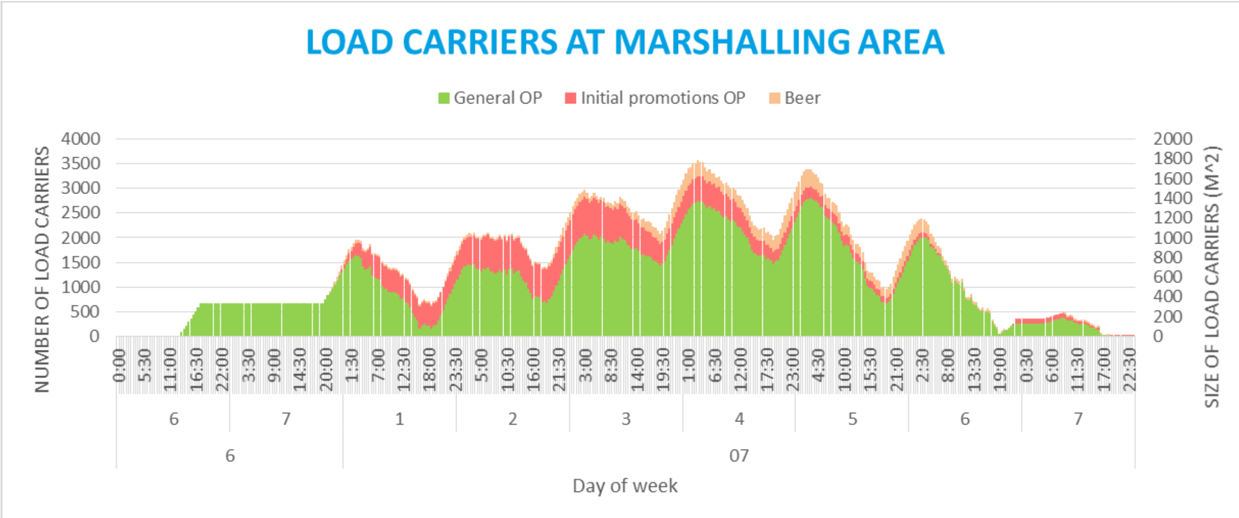


Figure XI.10 Load carriers at marshalling area scenario 5

Scenario 6: Decrease of the average order pick time by one minute using the settings of scenario 3 (average week)

Order picking general orders

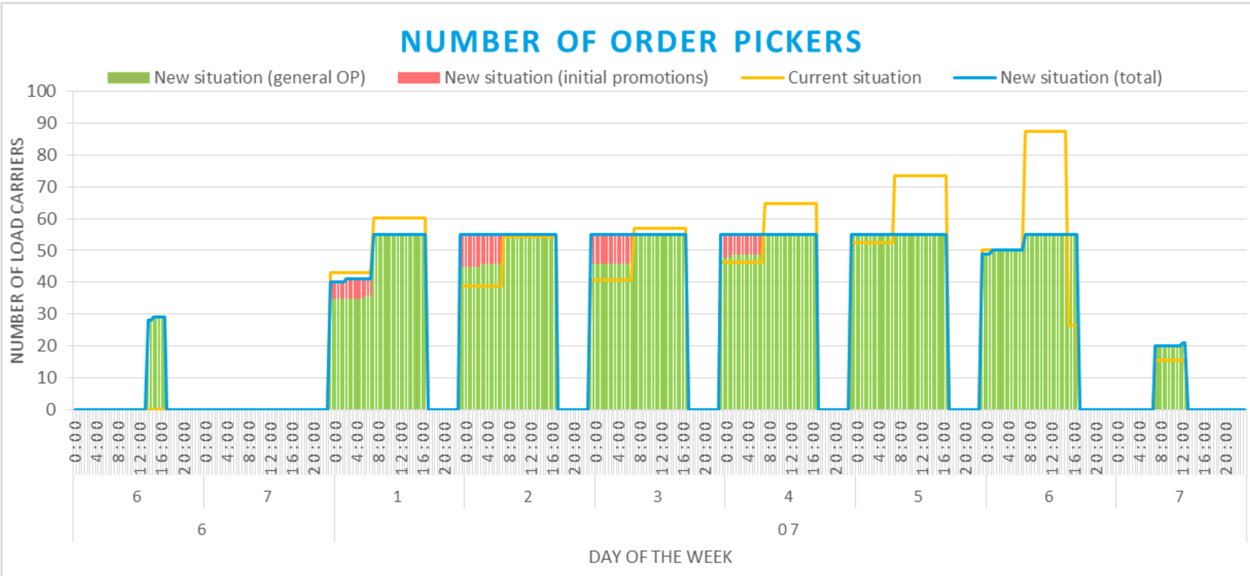


Figure XI.11 Production process scenario 6

Size marshalling area

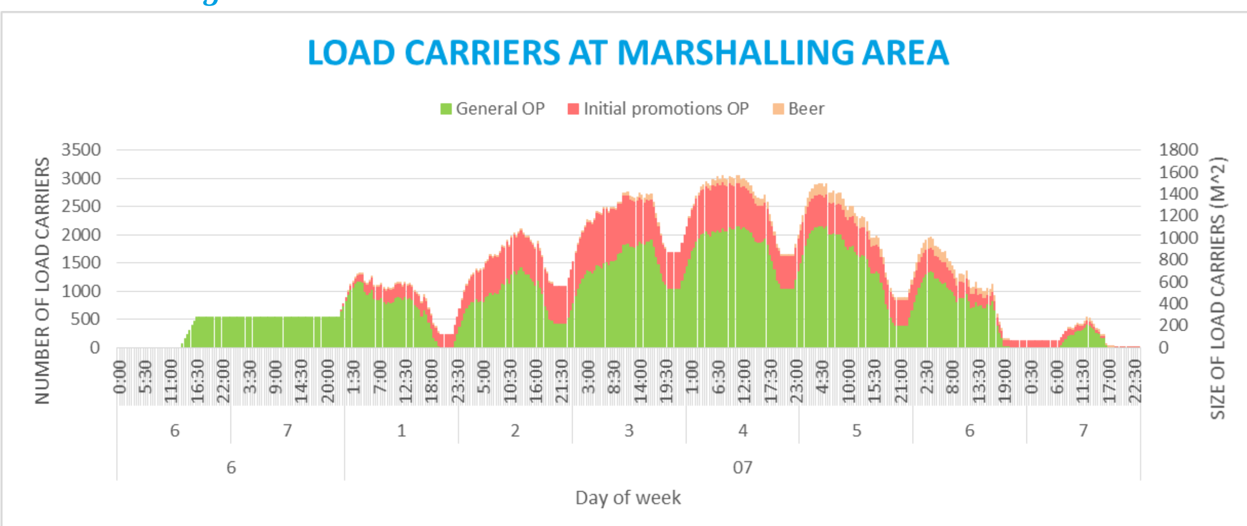


Figure XI.12 Load carriers at marshalling area scenario 6

Scenario 7: Maximum number of order pickers (maximum week)

Order picking general orders

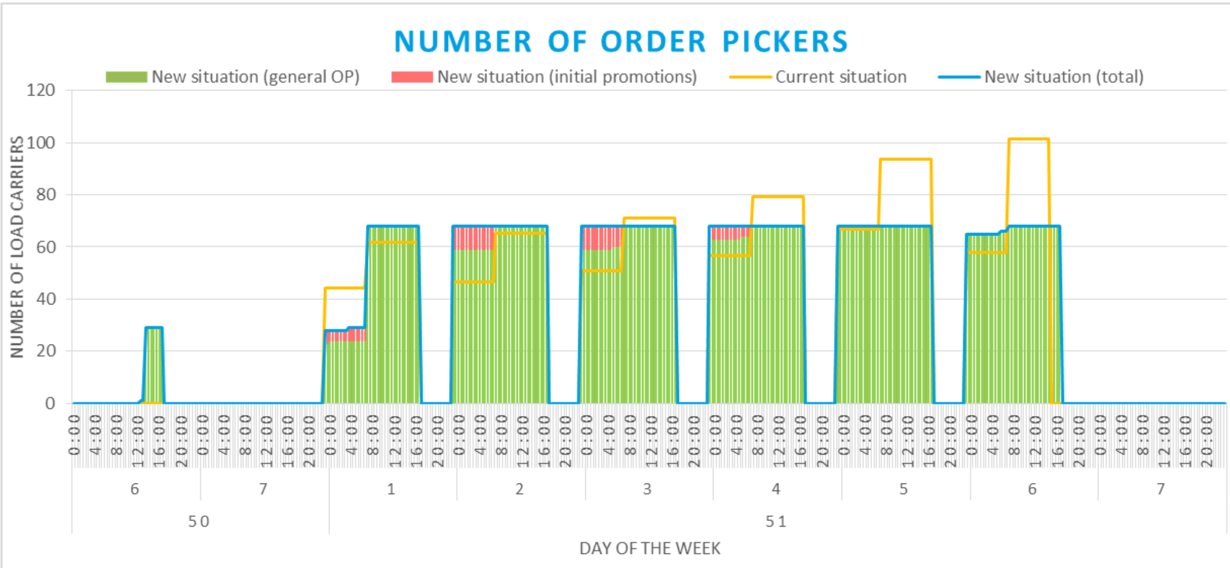


Figure XI.13 Production process scenario 7

Beer production

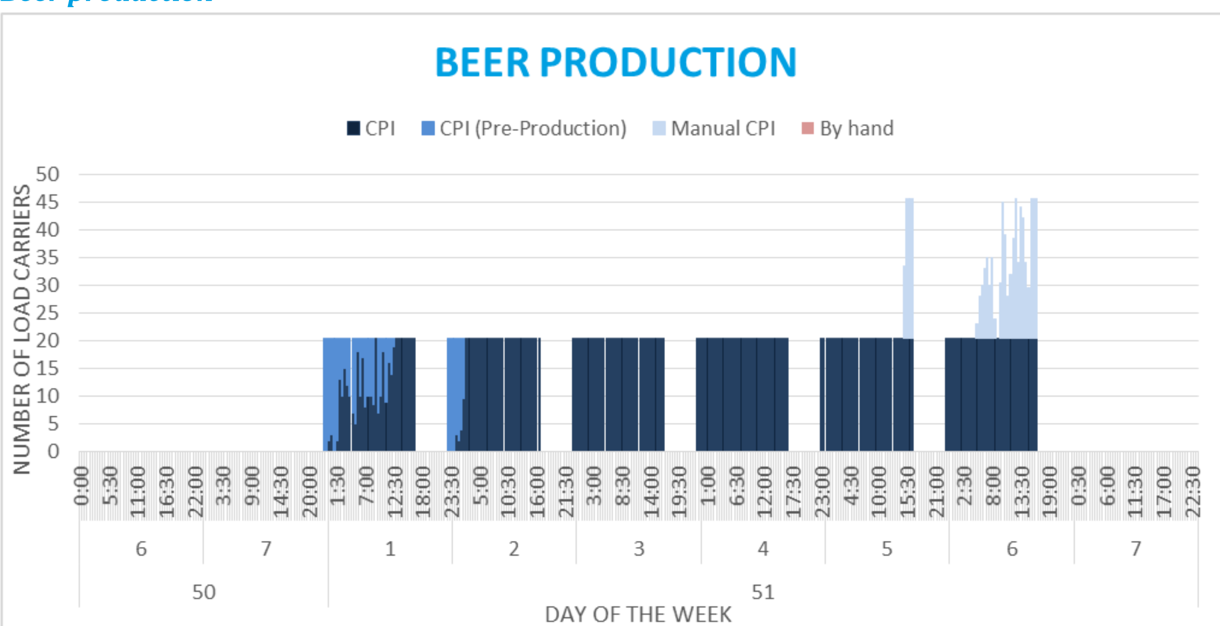


Figure XI.14 Beer production scenario 7

Size marshalling area

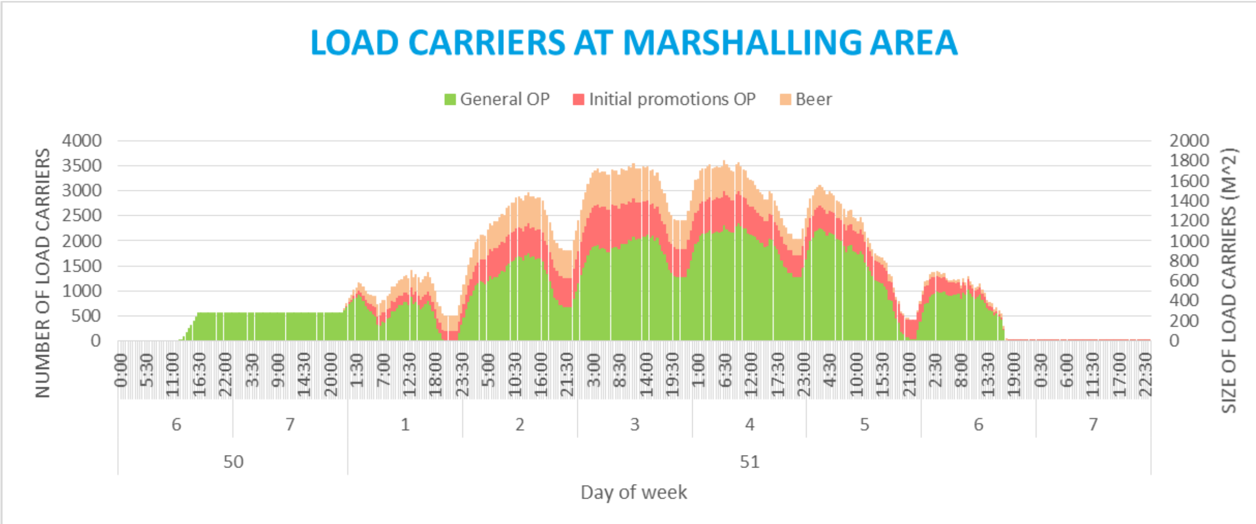


Figure XI.15 Load carriers at marshalling area scenario 7

Scenario 8: Maximum number of order pickers, initial promotions from Monday onwards (maximum week)

Order picking general orders

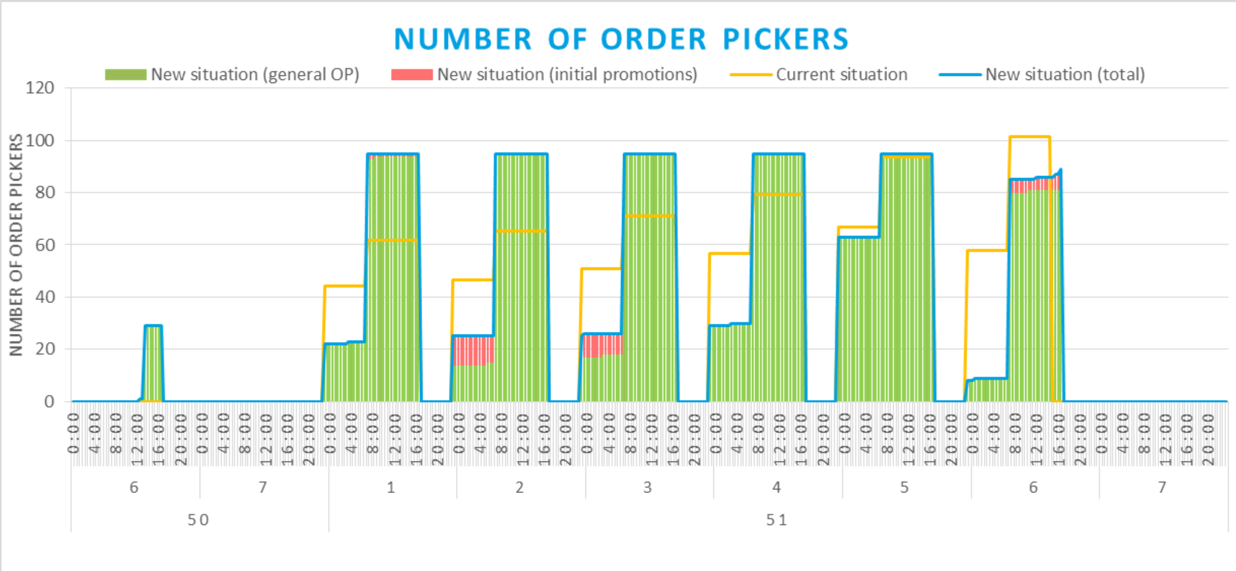


Figure XI.16 Production process scenario 8

Size marshalling area

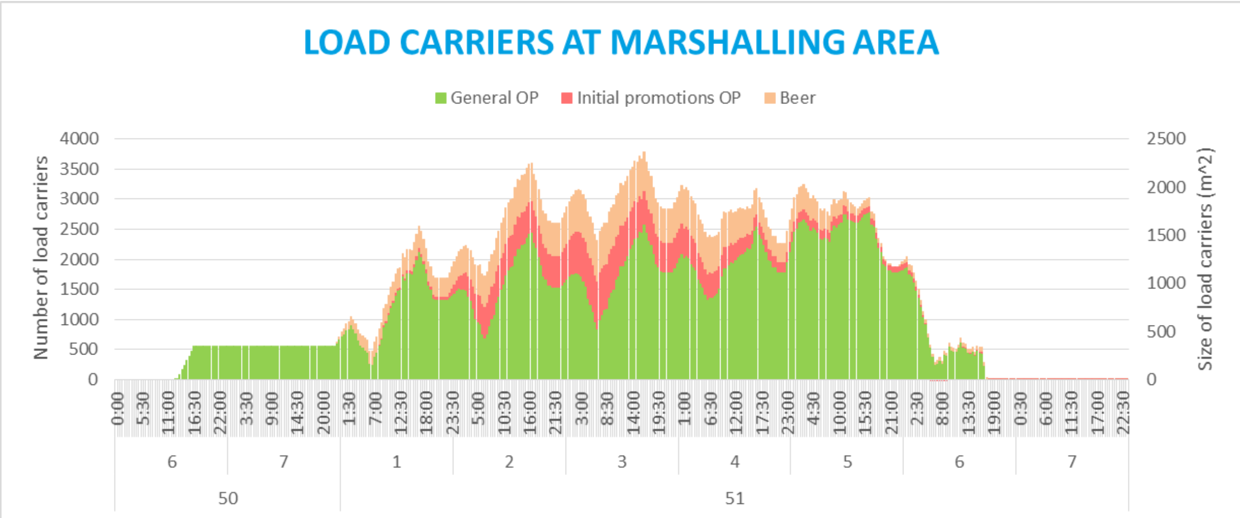


Figure XI.17 Load carriers at marshalling area scenario 8

Scenario 9: Minimum number of order pickers, initial promotions from Monday onwards (maximum week)

Order picking general orders

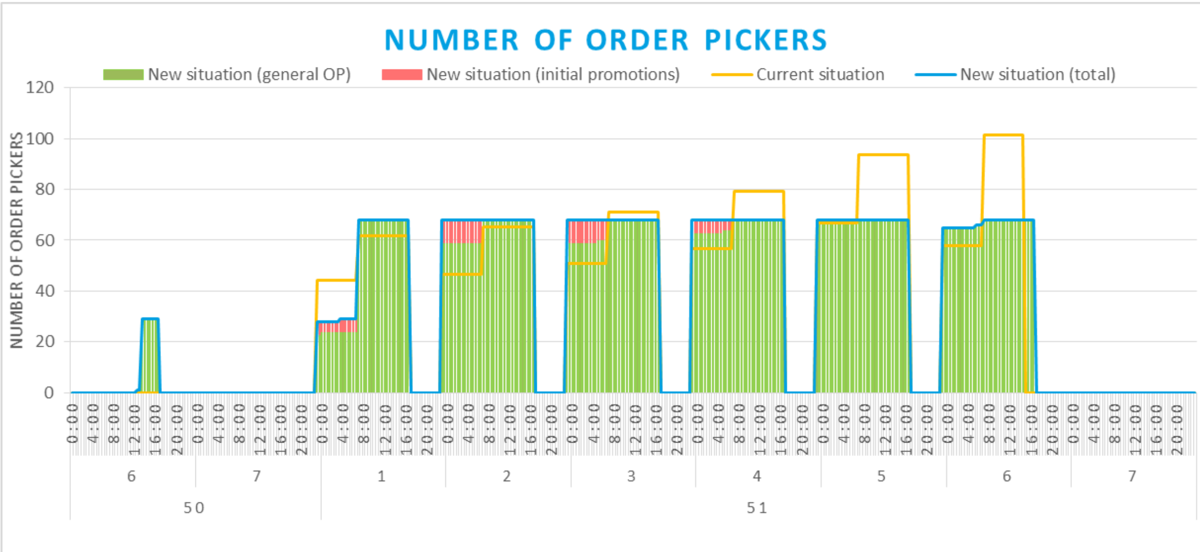


Figure XI.18 Production process scenario 9

Size marshalling area

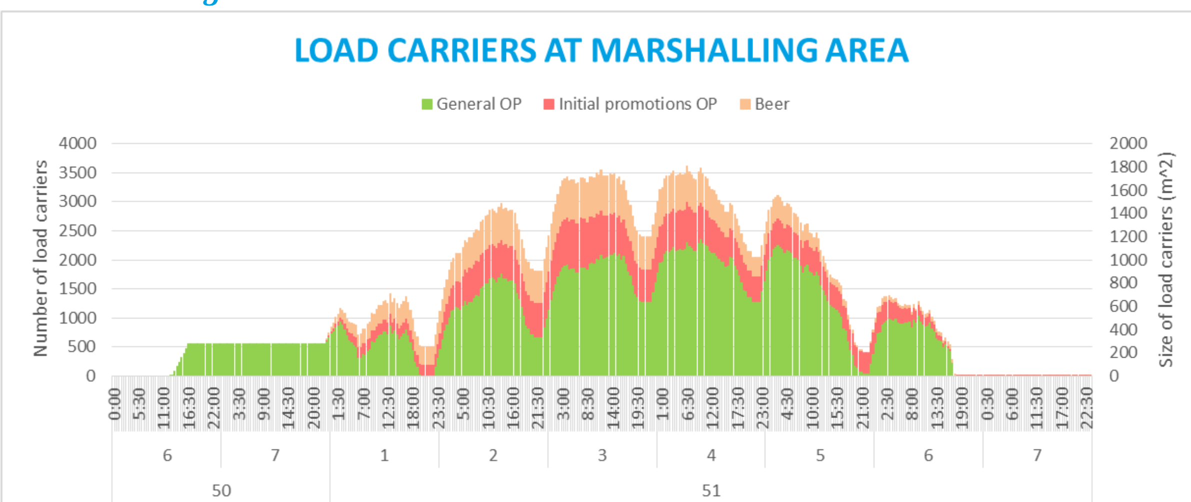


Figure XI.19 Load carriers at marshalling area scenario 9

Scenario 10: Lowest required size of marshalling area (maximum week)

Order picking general orders

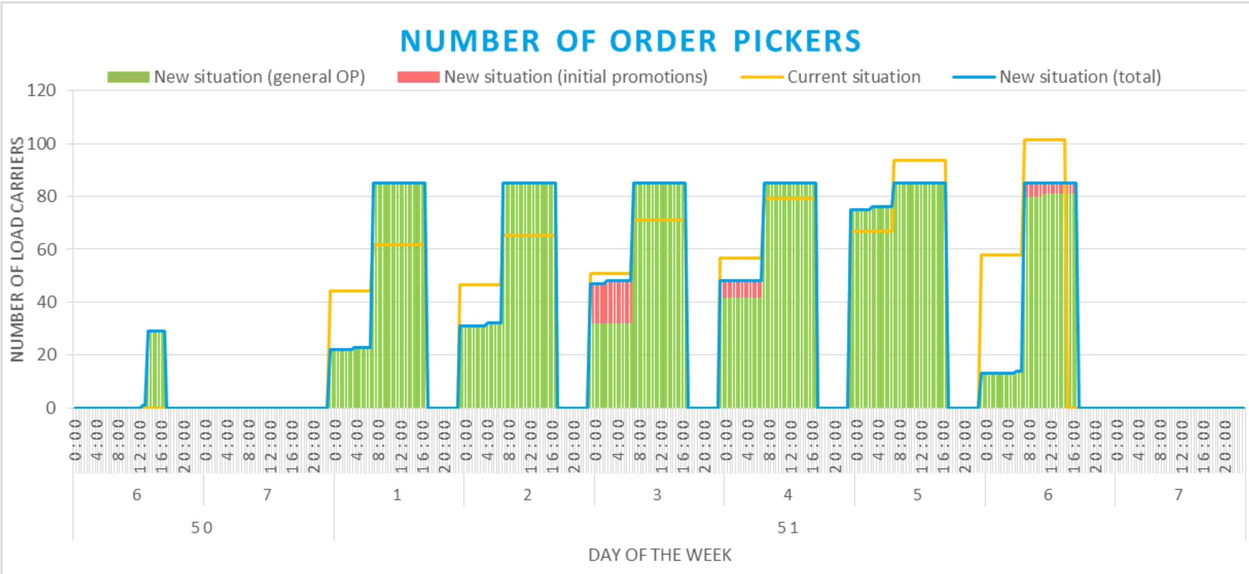


Figure XI.20 Production process scenario 10

Size marshalling area

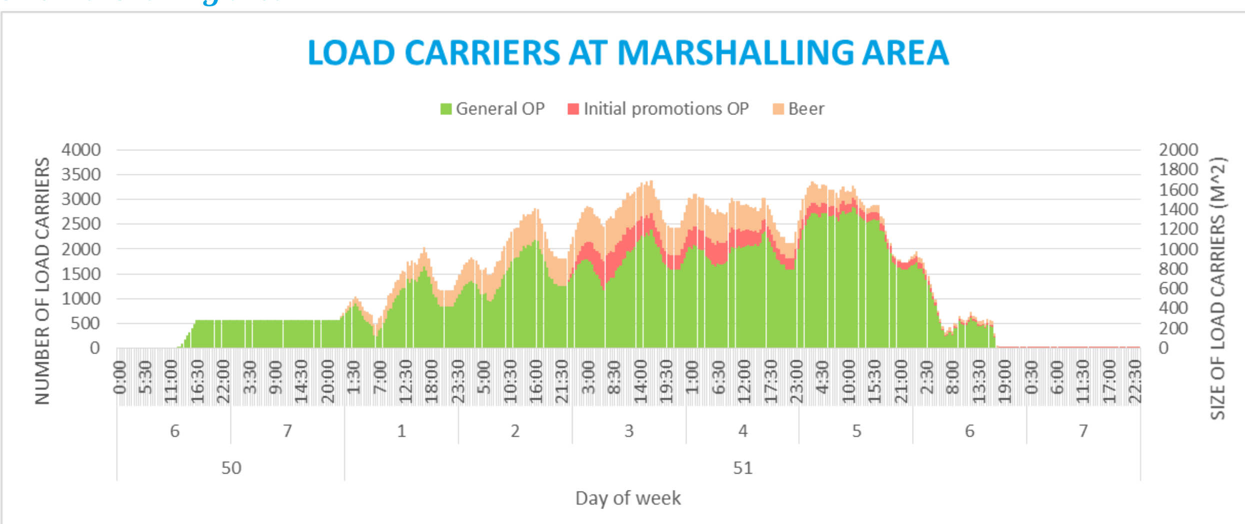


Figure XI.21 Load carriers at marshalling area scenario 10