MASTER

Shifting from local distribution to network distribution in a floriculture environment

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Shifting from local distribution to network distribution in a floriculture environment

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Abstract

This study investigates the opportunities for reducing the workload in a distribution process by changing from local distribution to network distribution in which products are distributed to the location of the buyer instead of the products being distributed to the location of auctioning. The current situation of the distribution process at one location in the network is extensively analyzed. In the second phase this analysis is used to model a simulation of the selected redesign in order to examine the influence of the change of distribution on the total number of effective distribution workers. The workload is the key performance indicator for the system and it is expressed in the number of effective distribution workers needed. The study provides a valuable insight in the current process and examines the possibilities for more effective use of the workforce by introducing network distribution.

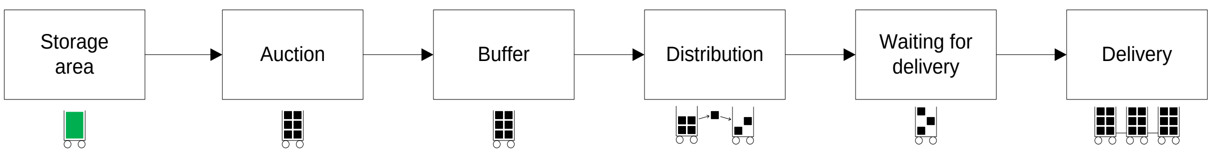
This report has been made suitable for publication. Therefore the outcomes are shown without numbers. Furthermore, relevant information throughout the text, names, and appendices have been labeled confidential and are masked in this version.

Management Summary

Every day at 6 o'clock the auctioning of flowers and plants starts at the sights of the company. Thousands of flowers are supplied by the growers in the preceding hours, which are then offered to the buyers in the floriculture network. The buyers want their purchased products as soon as possible after they bought the products in the auction process. They can then process their bought products and service their own clients. In order to get the products quickly to the buyers, a sophisticated distribution process is set up, within the company, in which the trolleys supplied by the growers are distributed among the buyers of these products. This distribution process has evolved over the years into the state it is currently in. This distribution process is not exactly the same at every location, due to the fact that these locations where autonomous companies in the past.

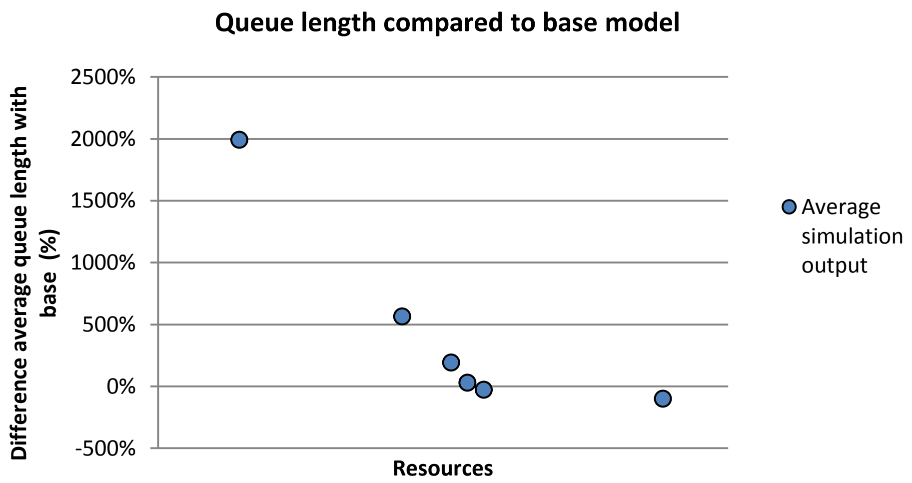
This project looks at optimizing the flows of flowers which occur after auctioning. Every buyer buying its flowers at an auction of the company has a defined exit point from the company network. A buyer is either situated in sight of the company, which is consequently the exit point for this customer, or a buyer is located outside an auction location, then the nearest location is its exit point.
When a buyer purchases products at an auction location which is not its exit point, these products have to be transported. This is defined as Inter Auction Transport type 4 (IAT 4) (Jonkman, 2010). Currently these flows happen outside the network of the company, which means buyers arrange this transport with LSPs.
The objective of this research project is to assess a new optimal situation in which these flows are incorporated in the company network, in other words to investigate the implications of changing from local distribution to network distribution. The effect of the new distribution situation should lower the work intensity for the distribution workforce. At this moment the high workload results in short working days for the distribution workers. A situation in which fewer workers can be held occupied for a longer period of time is more desirable. The adjustment of the type of distribution has a great influence on the internal distribution process at every location of the company.

For this research project the distribution process at [redacted] is chosen for analysis. The other locations are assumed to have the same characteristics as [redacted]. In this process the auctioned trolleys are distributed over trolleys related to the buyers participating in the auction. The auctioned trolleys are fed into the buffer of the distribution process directly after auctioning.
The distribution process is roughly as follows. A distribution employee picks up a trolley and checks if the trolley is complete. Subsequently he drives to the first aisle, where the trolley location of the first buyer is located. There he transfers the number of bins the buyer purchased to the trolley on the location. The process is continued until the auctioned trolley is empty. The distribution employee drives back to the buffer to pick up a new full trolley and the process starts over again. The process is shown in the following figure.



Several options for redesign of the distribution process are discussed, all with the objective of reducing the workload for the distribution workers. All options also include the transitions from local distribution to network distribution. One of these options is chosen for analysis, which is the option of the release of IAT 4 before distribution. In this redesign option a distribution worker takes of all IAT 4 transactions from the trolley in a designated area after which he distributes the remaining content of the trolley in the existing manner. The IAT 4 transactions are loaded into trucks and transported to the location in which their buyer has its exit point. The incoming IAT 4 products, at all locations, are distributed after the internal distribution process is finished.

The redesign and the current distribution process are modeled in a simulation experiment. The performance of the simulation of the current distribution process is defined by its average queue length. The first runs of the redesign simulation show a system which has a lower occupancy rate compared to the current situation. This is a first indication the redesign lowers the workload in the distribution process. Also the redesign has a much lower average queue length compared to the current distribution process.
In the sensitivity analysis the workforce in the redesign model is decreased in order to find the same performance as the current distribution process. In other words, the number of workers for the redesign is determined with which this system has the same average queue length as the simulation of the current distribution process. The following figure shows the relative difference in queue length between the simulation of the redesign and current situation.



The figure shows that the workforce can be lowered down to 154 employees and still performs the same as the current situation model. This is a reduction of the workforce of 7.23 %. When lowering the workforce even more the figure shows a rapid expansion of the queue length, something which is not desirable.

In addition to the reduction possibilities for the workforce, the workers are occupied for a longer period of time. This is also one of the desires of the distribution department at the company. Currently they can offer these workers only short working days.

Finally the results of the simulated redesign are compared with the characteristics of another redesign option. In this option the distribution process remains the same and the IAT 4 products are taken from the process at the end. However, this option results in a lot less smoother process because the distribution process has to be totally finished before all IAT 4 products can be shipped. In addition to this unwanted process characteristics, there is no reduction of the workload and consequently no option to reduce the workforce.

Acknowledgements

This thesis is the result of a graduation project carried out for the Master of Science in Operations Management and Logistics at Eindhoven University of Technology. I am grateful I was given the opportunity to conduct this project at the supply chain development department of the company. The flower industry is something the Netherlands is very well known for. However, only a small part of the Dutch citizens is aware of the things happening in this industry. Before I started my master thesis I only knew of the existence of the flower industry in the Netherland. This thesis provided me an opportunity to learn a lot about a very dynamic industry as well as the company acting as a platform for this industry, the company.

This thesis marks the end of my life as a student and at the same time a new period with new opportunities and challenges begins. I am very grateful I can finish a great period as a student in Eindhoven at such an interesting and challenging organization. I think it is of great value to conduct your graduation thesis within a company. It results in a lot of new experiences and it provides an ideal bridge between your theoretical education and the working environment lying ahead of you.

I like to thank Edwin Wenink for providing me the opportunity to perform my project at this department, as well as his enthusiastic and valuable input given during the project. Our inspiring meetings always provided me with new ideas to proceed. I thank Aard Jan de Leeuw van Weenen for supporting me with his practical experience and insights. Also the opportunity to participate in the day to day operation was of great value and fun.

Numerous other colleges helped me a lot with all the questions and requests regarding my thesis. They all helped me without hesitation and always tried their best in fulfilling my requests. The friendly atmosphere provided a great place for me to work in.

I thank my first supervisor Tom van Woensel for his guidance, support and feedback during my graduation process. His knowledge and experience as well as pragmatic insights made sure I kept on track and reached the final goal in the end. Moreover, I like to thank Nico Dellaert who provided me in our several meetings with very important insight, which act as important input for the final solutions.

Above all, I like to thank my family and friends for their relentless support during my graduation project and the long way in getting there. The interest they showed in my project and their encouragements helped me to reach the final goal. Special gratitude goes to my parents, sister and my girlfriend Leonie. It was great having you there for me.

Casper Roebroek.

Eindhoven, December 2012

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1 Introduction

This research design project has been carried out within the department of supply chain logistics (ketenlogistiek) of the company in collaboration with Eindhoven University of Technology. The main objective of the project is to investigate the possibilities for reducing the workload in the company's distribution process by introducing network distribution as opposed to the current local distribution.

1.1 Company introduction

The Netherlands is the heart of the international floriculture sector. It has an intricate and high-quality network of companies, ranging from breeders and growers to sales experts and export firms, representing every aspect of the business. The Netherlands is the place where supply and demand comes together, from Europe and beyond.

the company is the largest and most successful flower auction in the world, through which approximately 44 million cut flowers and 4.8 million houseplants and garden plants are traded daily. the company is market leader and key player in the international floriculture sector (Qin, Jiang, & Yang, 2010). Also for the economy of the Netherlands the company is an important player. The Greenport the company is, with Schiphol airport and the port of Rotterdam, one of the three economic 'main ports' of the Netherlands. With only 0.008 percent of the world's land area, the Netherlands is the world's third largest net exporter of agricultural goods and the leading supplier of cut flowers, accounting for approximately 65 percent of the world's market share (Ministry of Foreign Affairs, 2007).

the company is a flower auction company in the Netherlands and serves as an intermediary service between thousands of suppliers and customers each day. It is a cooperative and it is owned by the growers and suppliers. the company guarantees payment security and speed to its suppliers and therefore owners. Next to this the company serves as a transparent price setting entity. The auction clock determines the market price for numerous products.

According to the mission statement the cooperation has as goal the realization of maximum sales revenues against as low as possible costs. the company wants to maintain and strengthen its customer focus and decisiveness. Therefore, many improvement projects are carried out throughout the company. This to optimize the chain processes as well as the local processes.

the company has five different locations in the Netherlands and one in Germany: Aalsmeer, Naaldwijk, Rijnsburg, Bleiswijk, Eelde and Herungen (Rhein-Maas). Of these six locations Aalsmeer, Naaldwijk and Rijnsburg mostly serve the export market; Eelde, Bleiswijk and Herungen (Rhein-Maas) are regional locations and serve mostly their surroundings (Figure 1).

Figure 1: Location of the company sites

Next to the physical auction the company Connect is also part of the cooperation. This part of the business supports a direct flow between supplier and buyer. In this way the supplier can always fulfill the needs of the buyers and the price is fixed. The suppliers get their money directly after delivery from the company.

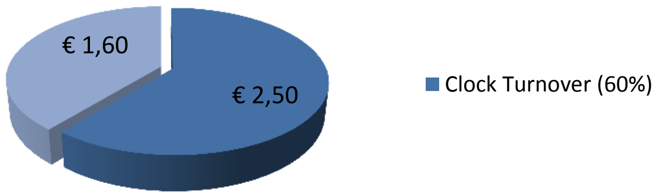

Figure 2: Total Turnover the company 2010 in billions

In 2010 forty percent of all turnover of the company was generated through the connect division. Large retailers do not want to take the risk of buying on the clock and they need a particular set of flowers or plants at a defined point in time. Supplier and buyer make an agreement, via Connect, about price and delivery date.

1.2 Floriculture Supply Chain

the company is the platform between the growers and suppliers and the buyers. In Figure 3 an overview of the floricultural supply chain is given.

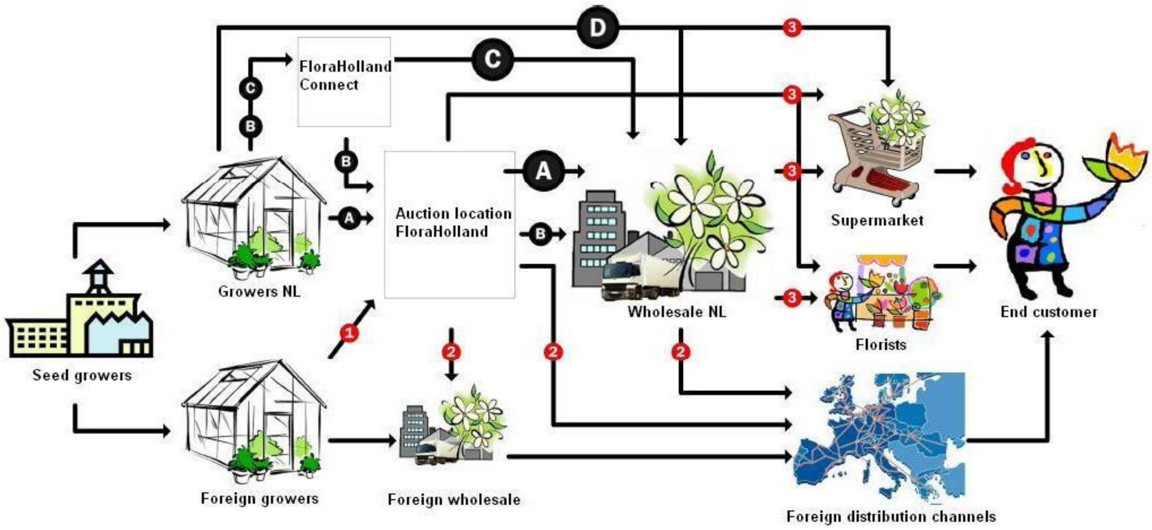

Figure 3: Overview of the floricultural supply chain (Adapted from Eindrapportage Besparen in Ketens –Sierteeltsector, EVO, 2009)

The flows in the FSC are categorized in the following four groups. These groups are labeled A, B, C and D in Figure 3.

A. Clock flows: Growers supply their products at one of the locations of the company. These products are then auctioned in which the price of the product is determined dynamically using a Dutch auction (The price starts at a high value and lowers until a buyer purchases the product).

Jonkman (2010) gives an extensive explanation of this process. The clock flow is of main concern in this project.

B. Connect Flows: A buyer places an order for flowers or plants directly at the grower. the company acts as financial middle man. These flows are processed in the the company distribution network.
C. BDO (Buiten Distributie Om) Flows: This flow represents the products sold with the use of the company Connect which do not enter the distribution network of the company. The products are directly delivered at the location of the buyer or an LSP on behalf of the buyer.
D. BVO (Buiten Veiling Om) Flows: When a grower sales his product directly to a buyer without involving the company. When a grower is part of the cooperation he is allowed to do this for only small volumes.

The red numbers in Figure 3 (2) represent the following:

1. Import
2. Export
3. National sales flows

In the literature about the floriculture industry a few topics stand out. First a rapidly changing landscape of markets and production locations can be observed. New markets emerge quickly and traditional markets face changing demands and saturation. Second point of interest is the rapid change in technology and the resulting change in the trade processes itself. Traditional Dutch auctioning is losing market share and the behavior and location of the buyers evolves.
These changes in the landscape ask for an agile cooperation which is able to react to these changes occurring in the industry.

1.3 Structure of the report

The remainder of the report is structured as follows. Chapter 2 starts with a description of the problem environment followed by the introduction and definition of the problem. A scope is defined as well as the expected deliverables. In chapter 3 an overview of relevant literature is given. Some sections are directly used in this project whereas others are relevant for the organization as a whole. Chapter 4 provides an extensive analysis of the distribution process. Relevant parameters are defined which will be used in later sections of the project. In chapter 5 possible directions for redesign are discussed and finally one is selected to be analyzed. In chapter 6 a simulation model for the chosen redesign is constructed and its components are explained. The results and conclusions of this simulation experiment are discussed in chapter 7. In chapter 8 conclusions are drawn by reflection on the research questions. In addition, recommendations for implementation of the redesign are given and directions for further research are outlined as well.
In the text references are made regarding tables and figures. Whenever the reference in the text is not on the same page as the table or figure the page number of the referenced object is added between parentheses.

2 Introduction of the problem context

In this section a problem statement with sub questions will be defined. This problem statement is the starting point for the actual research. First a current situation will be described; subsequently the problem definition is discussed.

2.1 Current process

the company consists of multiple locations and every location has its own way of handling the goods which is mainly a consequence of being separated auctions in the past (an overview of this history is given in Appendix A). However, the main processes are roughly the same at the different locations (later the differences will be described in detail). In this section the three departments (in general): Supply (Logistieke Dienstverlening Aanvoer, LDA), Distribution, Delivery (Logistieke Dienstverlening Kopers, LDK) will be described.

2.1.1 Supply (Logistieke Dienstverlening Aanvoer, LDA)

Until 4 am suppliers can deliver their flowers and plants at the docks of one of the locations of THE COMPANY. When the trolley is at the arrival dock it is checked by an employee of this department. The barcode is scanned and now it is under control of THE COMPANY. Subsequently the trolley goes to the cooling cell and they are checked for quality. When the auction starts the trolleys are transported by the use of a chain conveyor to the clock or directly to the distribution department. This process is almost the same on the different locations.

LDA has a few key objectives. The first is getting flowers in the cooling areas as soon as possible. The dock areas and buffers are checked every few minutes to get the flowers into the cooling areas within the agreed times. The checking department assures that buyers actually get what is presented to them. To make sure the auction process runs smoothly all trolleys have to be sorted in the right way.

2.1.2 Distribution

All trolleys which are sold on the auction clock are directly transported to the buffer of the distribution department. Before they go into the buffer a set of tickets is added to each trolley. These tickets provide the distribution employees the information they need to distribute the flowers and plants. In [redacted] distribution works with the system Voice (an overview of the use of Voice is given in Appendix C). In other locations distribution employees still only use tickets for the process. In the future they also will start to work with Voice.

The distribution process is roughly as follows. A distribution employee picks up a trolley and checks if the trolley is complete. Subsequently he drives to the first aisle, where the trolley location of the first buyer is located. The process is continued until the trolley is empty or the trolley goes to the aisle with rest buys. The distribution employee drives back to the buffer to pick up a new full trolley and the process starts over again.

When a trolley of a buyer in an aisle is full it is checked by an employee and it is transported to the right delivery lane (goot). Each lane or set of lanes corresponds with a buyer or a set of buyers. These lanes are situated at the sides of the distribution floor and the output of the distribution is buffered here until it can be transported to the box of the buyer.

There are special drivers who only handle trolleys which are bought in total, these called 'eenkoops' (one buys). These trolleys go directly to the right lane en therefor skip the distribution process.

Between the different locations of the company there are some differences in way of working.

- [redacted]: Distribution works with the Voice system, which means they get all information through there headset. The system is operated with commands. Flowers and plants are strictly separated and both have their own distribution area. There are no flows between these areas what so ever. The scheme of this process is shown in Appendix C.
- [redacted]: [redacted] is the largest location of the company and therefore it has the biggest distribution area of all locations. The distribution process in [redacted] differs quite a lot with the process in

[redacted]. Trolleys with less than three buyers are transferred by hand (overzetten). Trolleys with up to approximately 7 or 8 buyers are distributed like in [redacted], except tickets are used to get information about transfer locations instead of Voice. Plants are distributed on the first floor. However trolleys with more than 3 buyers are transferred to the distribution area of the flowers and are handled there. Buffers are not automated like in [redacted] and trains are driven next to each other to form a buffer manually.

- [redacted] : flowers and plants are distributed together. This is mainly because [redacted] handles only a few plants. Buffers are fed by an elevator which brings trolley from the auction areas downstairs to the distribution area on the first floor. The process is the same as in [redacted], except tickets are used and not Voice.

The distribution process which is discussed above is shown in Figure 4. The small pictures below the process steps resemble trolleys, which are used in the distribution process. A trolley waiting in the storage area before auction is a uniform trolley with no details for the distribution process yet. At the auction the trolley is divided among buyers. This means the trolley contains *X* transactions after auctioning, which have to be distributed in the distribution process. During this process the transactions are transferred from the auction trolley to the trolley related to the buyer. This is shown at the 'Distribution' process step in Figure 4. Subsequently the transactions wait for a full buyer trolley after which they are delivered to the buyer in their boxes.

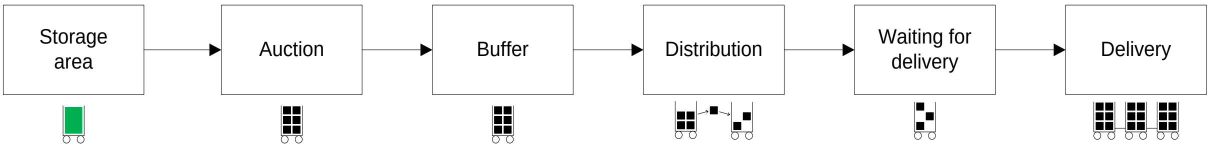

Figure 4: Distribution process

Especially workers in the distribution department work short periods. Most of them have part time contracts but in this time of recession they cannot fill their hours with the distribution work. Therefore they have to make hours in different departments or projects to work all their contract hours. In some cases this can cause a downturn in the motivation of the employee. This is powered by the fact that the distribution process starts at 6 am and people have to leave home very early.

2.1.3 Delivery (Logistieke Dienstverlening Kopers, LDK)

When the trolleys are in the right lane, LDK can deliver the trolleys to the box of the buyer. Drivers try to make trains as long as possible to get the most advantage from a single drive. Throughout the building there are a few decoupling points. So drivers bring trains from the distribution area to a buffer somewhere in the building. Other drivers bring trolleys from this buffer to the final buyer's box.
The LDK department is also responsible for empty equipment. The distribution department needs a sufficient amount of empty trolleys and the LDK maintains the buffers with empty trolleys.

2.2 Problem definition

In this section the main problem is introduced, followed by the research questions and expected deliverables.

2.2.1 Main problem definition

At 6 o'clock the auction starts and buyers start to buy flowers and plants on the auction clock. Some of them are physically present on the tribune in one of the company locations, others buy their products from a distance using their computer. This is called Koop Op Afstand (KOA). When the flowers and plants are sold they go immediately to distribution to get them to the box of the buyer as soon as possible. The buyers have agreements with the company about the lead time of the delivery of flowers and plants from clock to box.

When a buyer is not situated in the place where he bought flowers (this means it is a KOA), the flowers have to be transported as quickly as possible from the location of auctioning to the site of the company where he has his box. This transport can be defined as Inter Auction Transport (IAT). Jonkman (2010) defined four different types of IAT, which can be found in Appendix B. The last type of IAT he describes is the type of IAT discussed in this section. This type of purchase will be defined as IAT 4 and called this way from this point forward. This transport of IAT 4 is mostly done by LSP's and in some cases by the buyer itself. This means the company is not part of these movements and therefore has no influence on these movements.

Within the logistics department of the company they want to see if the high workload in the distribution process can be decreased by optimizing the path from auctioning to delivering at another location. This means the current situation has to be assessed and subsequently one or maybe two alternative situations can be evaluated.

In the following section the workload in the distribution process is further outlined. In the distribution department the company's personnel starts to work in groups of dozens of people. They have to work hard to deliver full trolleys to LDK as soon as possible. The performance of the personnel is also monitored on an individual level. The amount of units distributed and the number and type of mistake are registered. The personnel is under a high pressure in this period. The combination of the lead times agreed with the buyers and the amount of processed flowers results in a rather short work period for the distribution personnel with high workload. Since personnel have to start at 6 am and sometimes only work a few hours, motivation can become a problem. The objective is to reduce the workload for the distribution process by redesigning this process. This objective will be further described later on.

LDK deals with the same problem, however to a much lesser extent. They also have to finish their job in a certain amount of time to meet the lead time, but the high workload is not as fierce as at distribution. This department also has a high workload during the morning in which they have to transport large quantities to multiple buyers. Currently, they need a large amount of buffers to cope with the supply from the distribution department.

2.2.2 Cause and effect diagram

The problems described above are summarized in the cause and effect diagram shown in Figure 5. The High workload in the distribution process is considered as the main problem.

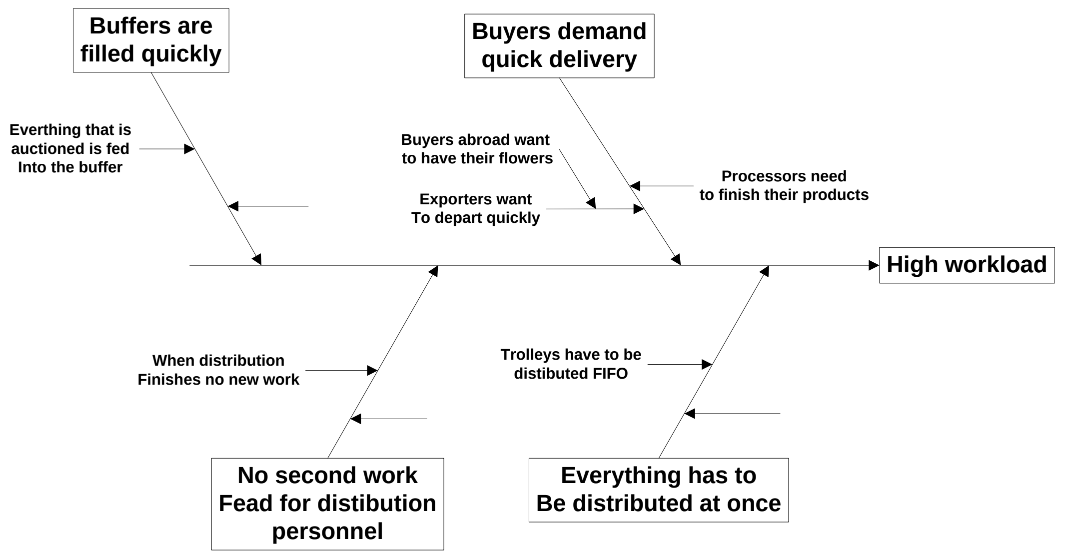

Figure 5: Cause and effect diagram

2.2.3 Scope

Since this master thesis project is part of a very big project (i.e. HubWays), it is very important to define the scope of this project.
This research will look at the distribution processes and in particular the flowers which have to go to another location after auctioning. The way in which the flows between auctions have to be managed is out of scope of this project.

2.3 Concepts

Before the main goal of the project can be formulated, first a few concepts need to be elaborated.
The current situation of the distribution process can be defined as *local distribution*. In this situation all flowers and plants which are supplied to a particular location of the company are distributed in this location. All trolleys are fed into the buffer of the distribution area and they are all processed by the distribution personnel. Even when the buyer is not situated in the location where the flowers are sold, it is handled as a local buyer in the current distribution process. In most cases the flowers go to the box of a LSP.
Another way of distributing the auctioned flowers can be described as *network distribution*. Goods bought by a buyer who is located in a different market place will be handled differently than in the current situation (local distribution). These goods will not be distributed in the market place in which they are auctioned, but in the market place were the buyer is located. In this concept goods of buyers located in the same location as were the goods were auctioned shall be handled similar as in local distribution.

2.4 Thesis goal

In the previous section the problem definition for this project is outlined. A project goal or overall objective of this thesis can now be formulated. Next to this central objective a few sub research question are formulated. The goal and sub questions are as follows:

*Explore the impact on workload in the distribution process by introducing **network distribution***

This main goal/objective can be split up in different sub questions.

1. Which possibilities for network distribution can be set up?
2. In which way do the processes have to be adjusted to achieve a logistic system which is able to perform network distribution?
3. What are the advantages and disadvantages resulting from this adjustment and which one outweighs the other?
4. What are the effects of changing to network distribution on costs and operations (e.g. number of handlings, failures, lead times)
5. Does the change to network distribution result in a flattening of the work pressure for the different departments?

The first two sub questions are to examine the implications of changing from the current situation (local distribution) to network distribution and maybe some necessary modifications that have to be made. The remaining sub question assesses if the change, whether it is practically feasible, solves the problem of the high workload.

3 Literature Review

In this section an overview of relevant literature is given. The discussed literature looks at the organization of the company as a whole as well as literature which is specific for the topic of this research assignment.

Distribution warehouse

A lot of companies have warehouses to store and distribute goods which they produce or sell. Products are collected for each customer by the picking of orders. Order picking can be described as follows: *the process of retrieving products from storage (or buffer areas) in response to a specific customer request* (Koster, Le-Duc, & Roodbergen, 2007). The cost of order picking is estimated to be as much as 55% of the total warehouse operating expense.

Lambert et al. (1998) state that more than 750,000 warehouse facilities exist worldwide. This ranges from cutting edge, professionally managed warehouses to company stock facilities and self-storage. Warehouses generate a lot of costs for companies, but still there are many of them worldwide. Lambert et al. (1998) outline in what way a warehouse is a contribution to the company as a whole. The ones important for the company are mentioned:

- Providing customers with a mix of products instead of a single product on each order (i.e. consolidation)
- Providing a buffer location for trans-shipments (i.e. direct delivery, cross-docking)

The first point represents the auction process in which a wide variety of flowers and plants is supplied by the growers every day. As an addition the company strives to be a more unified network out of which the buyers can choose their product and the growers can supply their goods on their most favorable the company location. This last mentioned point is also one of the reasons for the company to conduct this master thesis project in which an extensive analysis of the distribution warehouse will be made.

The second point from Lambert et al. (1998) represents the more logistical function of the company sites. Every day flowers are supplied which flow out the same day. In this respect the concept of cross-docking looks very interesting, something which will be discussed later in this review.

Tompkins et al. (2003) and Koster et al. (2007) discuss a set of typical functional areas and flows which occur in an average warehouse.

Cross docking

Cross docking is a warehouse management concept in which items supplied to a warehouse by inbound trucks are immediately sorted out, based on orders made by the customers, and loaded into outbound trucks headed for the customers. This means the items are no longer stored in the warehouse or in some cases the items are held in storage for a brief period of time, with a maximum of 24 hours. Relatively a low number of papers appear to be available about cross docking. This results in few rigorous approaches for planning cross docking operations (Yu & Egbelu, 2008). However, cross docking stays an interesting paradigm, especially with respect to the situation at the company.

Every day all flowers are auctioned at the company after all flowers have arrived. With the concept of cross docking in mind, it might be more beneficial to keep the flowers at the growers until they are auctioned. After auctioning the flowers can be transported to the nearest company sight where the items are distributed to the customers with the use of cross docking. This way the useless movement of flowers through the network can be reduced drastically. A lot of practical problems, like mobile inspectors, arise. These have to be solved, but the concept of cross docking is a possible improvement for the company's processes.

Routing methods

This distribution area of the company has a very distinctive layout. The floor map of the distribution area in [redacted] is shown in Appendix I. In this floor map a pattern of aisles and a main street can be seen. The process of distribution is in fact the same as order picking in a warehouse.

By using Petersen (1997) as a guideline six different routing strategies are considered, transversal (S-shaped), return, midpoint, largest gap, composite, and optimal. These strategies start as relatively simple to slightly more complex. The performance however depends on the conditions of the warehouse at which it is applied.

Vehicle routing problem

The vehicle routing problem (VHP) consists of designing *m* vehicle routes such that each route starts and ends at the depot, each customer is visited exactly once by a single vehicle, the total demand of a route does not exceed *Q*, and the total length of a route does not exceed a preset limit *L* (Laporte, 2009).

Vehicle routing with pickup and delivery (VHRPD) is an extension of the VHP. In its most basic form the pickup and delivery problem is build up out of a set of customers and a set of vehicles. In the case of pickup and delivery both the pickup locations as well as the delivery locations are represented by a customer out of the customer set. In the case of the vehicle routing problem either all the pickup locations or the delivery locations are located at the depot. This means within the pickup and delivery problem, each request specifies an origin and destination location (Ruland & Rodin, 1997).

For the vehicle routing problem with time windows (VRPTW) a lot of research is done in finding algorithms for optimal solutions of the problem (Desrochers, Desrosiers, & Solomon, 1992) (Desrosiers, Dumas, & Soumis, 1986).

In many situations a combination of the extended vehicle routing problems mentioned above can be observed. This can be described as a vehicle routing problem with pickup and delivery and time windows (VRPPDTW). A lot research is done in the past and new problems are constantly formulated. Lin (2011) formulates a heuristic for a VRPPDTW with the addition of different delivery resources. This requires a coordination of these resources, which also has to be added in the model.

Özer (2011) outlines an extensive analysis of the transportation network within the company.

Hub and spoke network

A hub and spoke model or network is a set of connections in the shape of a chariot wheel. The traffic moves along spokes which are all connected to the hub, the center of the wheel. The concept hub and spoke is used among different fields, with the most important being transport, telecommunications, freight and distributed computing, which is a field of computer science. For this section we look at the concept of hub and spoke within transportation. The first who looked at the hub and spoke concept as a quadratic programming problem was O'Kelly (1987). Sometimes a distinction is made between inter-hub routes and spoke routes. Inter-hub routes are called primary routes (trunk routes), whereas spoke routes are called secondary routes (Lin & Chen, 2007). In many other literature the line haul operations include the Inter-hub (primary) route and spoke (secondary) route, which are discussed earlier (Wasner & Zäpfel, 2003).

The theory on Hub-location models focusses primarily on the line haul design problem (Ebery, Krishnamoorthy, Andreas, & Boland, 2000). This means the part of pickup and delivery is left aside. However, hub location models assume that the vehicle routing problem does not affect the hub location problem (Wasner & Zäpfel, 2003).

One of the most important parts of the hub-and-spoke is the hub location-allocation. (Ebery, Krishnamoorthy, Andreas, & Boland, 2000) look at the allocation of multiple hub locations in a capacitated environment.

Ishfaq & Sox (2010) extend the hub location allocation problem with the incorporation of intermodal transportation. Intermodal transportation refers to the transportation of goods from point of origin to its destination by the use of more than one modes of transportation. Intermodal transportation is not the same as multimodal transportation. Multimodal transportation is choosing the mode of transportation from a set of different transportation modes. Once the transportation mode is chosen it is not changed anymore (Ishfaq & Sox, 2010).

Simulation modeling

A simulation model is implemented in a computer program. It is generally relatively inexpensive modeling approach, commonly uses as an alternative to analytical modeling. The tradeoff between analytical and simulation modeling lays in the nature of their "solutions," that is, the computation of their performance measures as follows:

1. An analytical model calls for the solution of a mathematical problem, and the derivation of mathematical formulas, or more generally, algorithmic procedures. The solution is then used to obtain performance measures of interest.

2. A simulations model calls for running (executing a simulation program to produce sample histories. A set of statistics computed from these histories is then used to form performance measures of interest

To compare and contrast both approaches, suppose that a production line is conceptually modeled as a queuing system. The analytical approach would create an analytical queuing system (represented by a set of equations) and proceed to solve them. The simulation approach would create a computer representation of the queuing system and run it to produce a sufficient number of sample histories. Performance measures, such as average work in the system, distribution of waiting times, and so on, would be constructed from the corresponding "solutions" as mathematical or simulation statistics, respectively (Altiok & Melamed, Simulation modeling and analysis with Arena, 2007).

Simulation in operations research

(Vieira, 2004) looks at the total supply chain and for each part of the supply chain a method of simulation modeling is discussed. Suppliers, manufacturers, retailers and consumer markets are modeled separately.
Takakuwa et al. (2000) give an example of how to simulate and analyze non-automated distribution warehouses. Their approach consists of three major steps in which first the relevant parameters are determined. Subsequently the input data for the simulation has to be derived and finally the simulation model can be built.
Although simulation and supply chains are well-studied subjects, both by industries and academia, simulation of supply chains has not been treated with much frequency, perhaps because of the complexity of such systems (Vieira, 2004).

4 Analysis

In this section an extensive analysis of the distribution process at [redacted] is depicted. This analysis will provide insight in the characteristics of the distribution process based on the data available. The parameters and distributions determined in this section will serve as input for the redesign.

4.1 Assumptions and starting points

Before any analysis can be made some important assumptions and starting points are outlined. They provide the base for the analysis. Assumptions are made throughout the entire text; however the following are of such importance they are assessed individually.

4.1.1 [redacted] as benchmark

The company's location at [redacted] will be used in this analysis. There are several reasons for this choice. First of all [redacted] is a large location (only [redacted] is bigger) within the company Network. In addition, the layout of the distribution area is relatively new in which the latest insights in process techniques are incorporated. The other locations of importance ([redacted] and [redacted]) are either already relatively the same ([redacted]) or will get the layout of [redacted] in the future ([redacted]).

4.1.2 Data selection

The analysis made in this section is based on data from 2011 and 2012. Özer (2011) made an analysis of the days of which the data should be used to make a good analysis. Özer (2011) selected five sample days to evaluate the performance of the proposed approach. Each day is taken from different times of the year to include flows with different characteristics, so to take seasonal effects into account. Therefore, the data is representative of different situations and effectiveness of the approach can be shown in all cases.

The commercial data used by Özer (2011) belong to Tuesdays of the 6th, 16th, 26th, 39th and 49th weeks. These days symbolize important days and different seasons, such as Christmas, end of winter and spring where a peak in the demand can be observed. This set of Tuesdays is supplemented with Thursday 5-10-2012, this is the dataset with which the first calculations were done.
In case of this analysis the objective was to use data as new as possible to get an up to date picture as much as possible. Therefor the auction data for the most recent days was requested. However, in week 6 and 26 there was a malfunction in the data warehouse which made the data for these days unavailable. To solve this problem 2 new days were selected as close as possible to the original dates. The datasets eventually used for this analysis are shown in Table 1.

Table 1: Datasets used for analysis

Date	Week number	Weekday	
09-27-2011	39	Tuesday	
12-06-2011	49	Tuesday	
01-31-2012	5	Tuesday	
02-17-2012	16	Tuesday	
05-10-2012	19	Thursday	Initial data set
07-10-2012	28	Tuesday	

4.1.3 Warm up period

The length of the warm-up period needs to be evaluated if the stage of the model at time zero does not represent the normal working conditions of the actual system that the model is representing. If this is true not all data from the data set can be used, data recorded in the warm up period has to be omitted.
Warm-up period is the amount of time that a model needs to run before statistical data collection begins. This warm-up period could be estimated through experimentation with moving averages (flow times,

throughput) and time series (WIP: work-in-process, buffer sizes). The point at which the model seems real for the first time could be estimated as the warm-up time (Mehta, Joines, Barton, Kang, & Fishwick, 2000).

Since the auction and distribution process at the company locations is starting up every morning, it is important to consider the phenomena warm-up period for this process. To see whether a significant warm-up process occurs every day at the company an analysis is made of the waiting time in the buffer, distribution time and total time. The first analysis is conducted for the data of 10-02-2012 and the result can be seen in Figure 6.

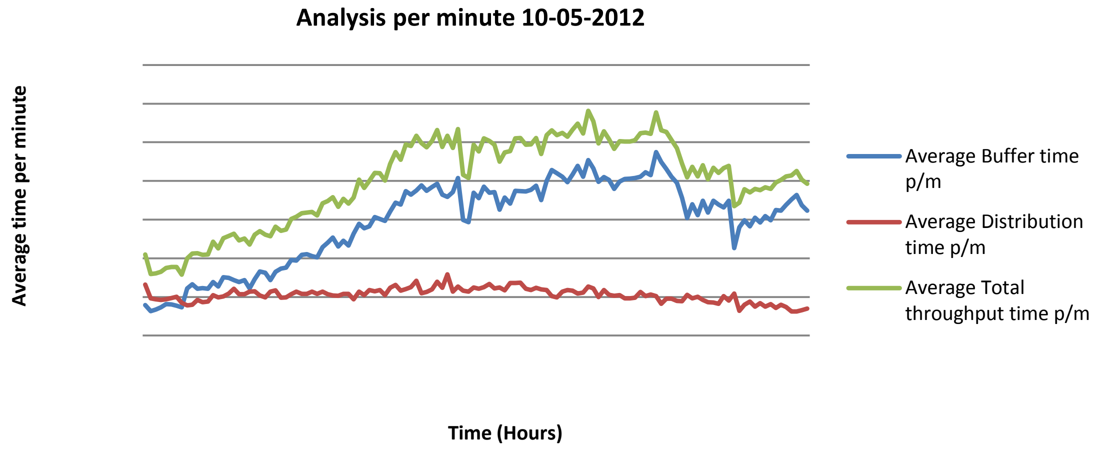

Figure 6: Distribution and waiting times

As can be seen in Figure 6 the average distribution time is rather stable throughout the entire time. The distribution time is stable almost directly from the start. The waiting time in the buffer increases during almost the first half of the process. This shows that the buffer fills up smoothly during the first hour of the workday. However, this behavior has no influence on the distribution process and therefore cannot be labeled as warm up period. It can be concluded that this process has no warm up period and therefore can be excluded from the consideration set. In Appendix E the warm-up analysis is validated. From Appendix G the conclusion can be drawn the process behaves the same on different days. Because it is concluded the process has no warm up period, all data from the data sets can be used for analysis.
The conclusion drawn regarding the warm up period is based on average throughput times. However, another important variable for the warm up period is the Work In Progress (WIP). This parameter is not known due to the lack of data, but it would be a good addition to this analysis.

4.1.4 **Customer locations**

Customers receive their purchases on the location where they process them, either delivered by the company or by others such as a LSP. This location can be a box inside the company network or a location outside this network. To conduct this analysis every customer needs to be linked to an exit point from the company network. To establish this exit point the assumptions made by Gaki (2012) are used. These assumptions are done since the commercial data could not provide exact information about the exit point of a trolley from the network. The following assumptions are made:

- Buyers located outside the company network are linked to a company location using the assumptions made by Dat (2010). Dat (2010) assigns the postal code areas in the Netherlands to a particular auction. This means a buyer outside the network is linked to an auction based on his address, more precise the postal code. The exit point from the network for this kind of buyers is assumed to be the nearest auction location.
- Box owners can be divided into two groups: buyers with a single box and buyers with multiple boxes scattered over more than one auction. Buyers with a single box have their exit point at the auction in which they are situated. For buyers with multiple boxes a largest box is defined, this is

the box with the largest number of docks. For this analysis the database from Florecom is used. It is assumed that this largest box is the exit point for the corresponding buyer as well.

- The last group of buyers is the international buyers. Due to the growing wealth in Eastern Europe and improving communicational facilities, these buyers are growing in number. International buyers usually collaborate with an LSP or with other growers to receive, handle and forward their products abroad. The company's Import Handling department provided most of the handling locations for international buyers. The exit point for these buyers is based on this information. For the buyers whose handling location was unknown, it is assumed that [redacted] was the network exit point for their products.

4.2 Analysis current situation – Total distribution process

In this section an analysis of the total distribution process in current situation is made which will act as a preparation for the redesign. The analysis of the current situation has been an iterative process in which looking at the redesign options and the still to be made simulation models acted as a continuous feedback loop for the analysis. This means some parts of the analysis will be used in a more extensive way for the redesign compared to other parts.

4.2.1 The distribution process

At first an analysis is made of the distribution process at [redacted] to get a better view of the events which play an important role. This analysis is shown in Figure 7 (18).
The first part of Figure 7 is the clock process which can be seen as process with a queue of zero and the input is always the same input as output ($\lambda \triangleq \gamma$). In this process buyers purchase their flowers by bidding on a particular cultivar and defining the size of their purchase. The buyer who issues the highest bid will get the desired amount of flowers. These purchases are the entities which will be followed through the process and form the basis for the analysis. The choice to focus on the purchases is because they stay the same all the way from auction to delivery at the buyer. Other entities like trolleys stay not the same, because their content changes and they do not follow the total path through the process.
The next part in Figure 7 is buffer and distribution. This represents the distribution process of emptying a full trolley by dividing its content among the trolleys of the buyers in the distribution area. The second part of Figure 7 also includes de queue for the distribution process and therefore the buffer and distribution process can be seen as a single process, single queue system.
The third part of Figure 7 is the time an entity spends waiting in the distribution area before it transfers from distribution to LDK (delivery). When the flowers are distributed they are transferred from the supplied trolley filled with the same cultivar to a buyer specific trolley. Every day a spot is reserved in the distribution area for each buyer. The trolley in this spot is filled with his purchases and when it is full the trolley is taken out of the spot and an empty trolley replaces it. This means entities spend time waiting until the trolley for its buyer is full. When this happens the trolley leaves the distribution area.
The last part of Figure 7 represents the process of delivery to the boxes throughout the respective company location. This part is out of scope of this project and therefore also of this analysis.

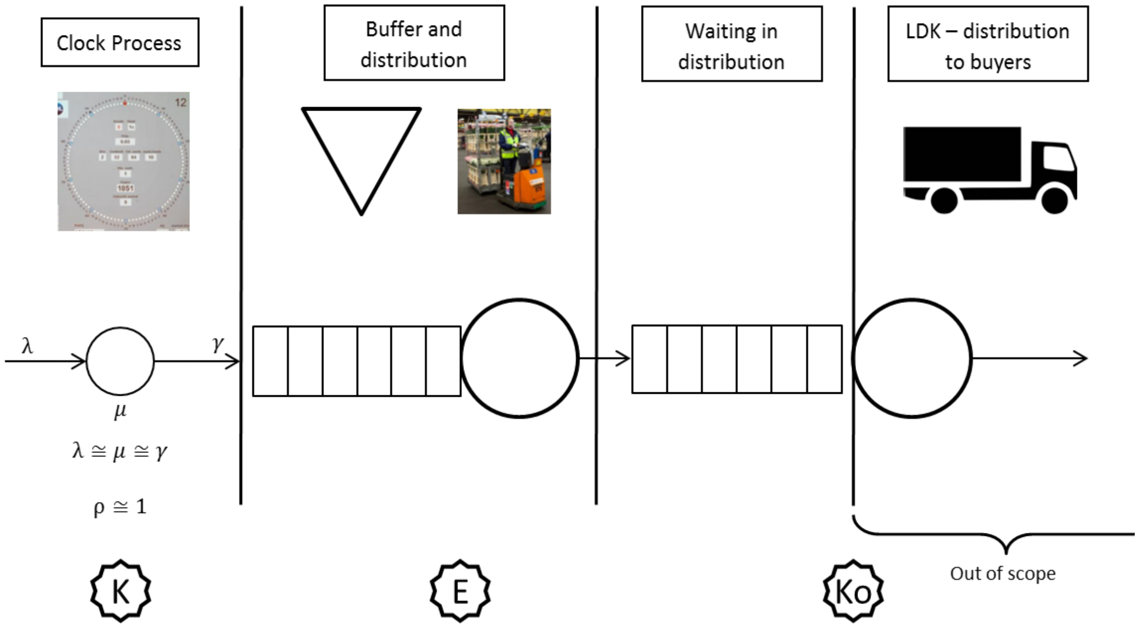

Figure 7: Analysis of distribution process

4.2.2 Measuring points

At the start of the analysis an identification of the availability of data from the distribution process is conducted. A selection of information was made based on the potential relevance for the analysis. In Appendix D the data set with all its rows and the first 25 records is given. It shows a lot of information like trolley numbers and names and administration numbers of buyers. For this moment however the measuring points in the distribution process are the most important. These times show at which moment in time an entity is at a certain location in the distribution process. These measuring moments are shown in

Figure 8 with corresponding names which are frequently used by the company personnel. The first time tag an entity gets is when it is created. This is at the auction when the purchase is made by the buyer, this moment is called T_K. The second measuring point is when a distribution worker takes a trolley from the buffer. He then scans the trolley in order to get the information from Voice (Appendix A) how to distribute the trolley. This measuring point is called T_E. The last time stamp is given at the end of distribution, to be more precise, the moment of transferring from the distribution into the gutters for LDK (delivery). This moment is called T_{Ko}.

In both Figure 7 and Figure 8 the labels K, E and Ko are included, which makes it clear how these two figures correspond to each other.

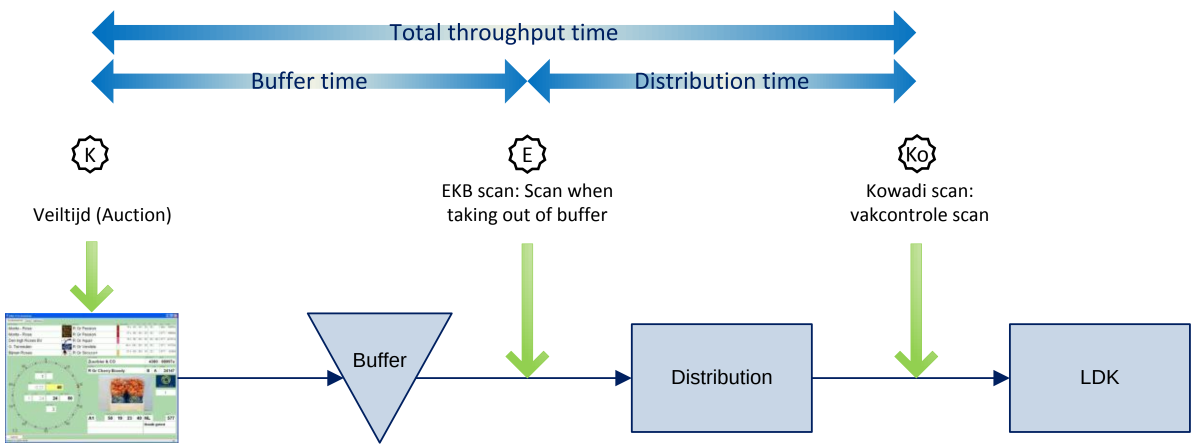

Figure 8: Illustration of measuring moments in distribution

4.2.3 G/G/m system for distribution process

With the measuring points shown in Figure 8 (18) the distribution process can be analyzed. First the process as shown in Figure 7 (18) is simplified to a G/G/m queuing system. This queueing system refers to a m-machine station with generally distributed inter arrival times and generally distributed process times. This system is shown in
Figure 9.

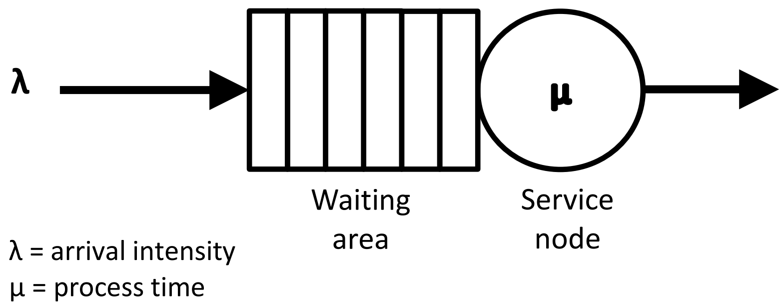

Figure 9: Distribution process simplified

4.2.3.1 Arrival rate

The arrival rate or arrival intensity λ represents with which rate entities arrive at the queue. In this case entities are purchases made by the buyers at the auction. To determine this parameter the arrival intensity within every minute of the auction process is calculated. This outcome is used to fit an arrival distribution. To find the right distribution the input analyzer of Arena simulation tool is used. The output from this analyzer is shown in Appendix E for a particular day. The output from all the analyzed days is combined by calculating an average mean and standard deviation. In Appendix E the fitted distribution for every day of the data set is shown in Table 20 (58).

This arrival rate is a theoretical rate, since the purchases do not move individually through the system. The products are transported and handled on trolleys; hence the purchases arrive grouped at the distribution process on trolleys. The arrival rate of the trolleys is assumed to be constant, because they are moved on a chain conveyor with a constant speed. Distortions such as pausing the chain are neglected. The average inter arrival time can be found in the final table in Appendix K and is equal to 2.95 seconds. In other words, every 2.95 seconds with a constant rate a trolley arrives at the buffer in order to be distributed.

4.2.3.2 Processing distribution

The distribution process at [redacted] is simplified into a single station with multiple resources. The average time a purchase spends in the distribution process, which includes the distributing by a distribution worker and the waiting time on a customer trolley, is called distribution time (see Figure 8 (18)). This distribution time is analyzed by fitting a distribution on processing times from the dataset, the results are also shown in Appendix E.

4.2.4 Product flows

In section 4.1.3 several assumptions are made about the exit point of the purchases made by a buyer. By linking a buyer to a certain auction location, every transaction gets an exit point as well. An analysis is made for every day of the dataset. The exit points of products for the individual days can be found in Appendix F, both for 'Meerkoop' as for 'Eenkoop'. The average flows are shown in Figure 11 and Figure 10. However this analysis section covers only the meerkoop data, for this topic the eenkoop (one transaction per trolley) analysis is included. Eenkoop trolleys are not incorporated in the redesign model but the outflows of the redesign supplemented with the Eenkoop flows represent the total flow between auction locations.

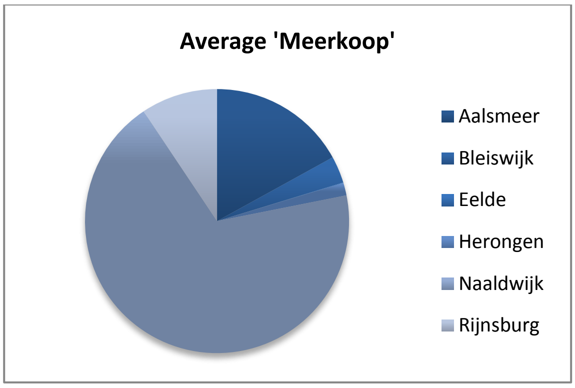

Figure 11: Meerkoop exit points

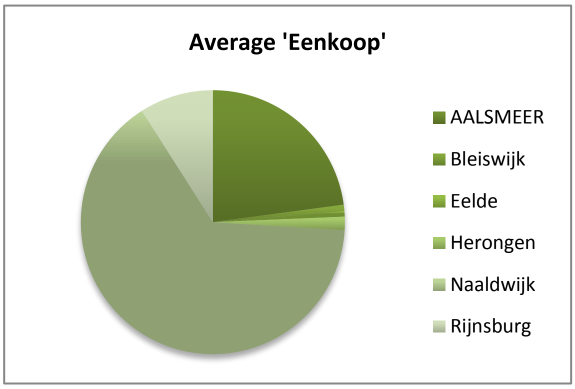

Figure 10: Eenkoop exit points

4.2.5 Conclusion total distribution process analysis

In the section above an analysis of the total distribution process is given. It provides a good insight in the behavior of the process. However, these parameters will not be used explicitly in the redesign later on. The following section will outline more precise parameters of the process. These will act as input for the redesign, but they are built on the analysis given in this section.

4.3 Analysis current situation - subsections

The previous section gives an analysis of the total distribution process. However, several more detailed parameters need to be analyzed to be able to construct a redesign. In this section parameters of interest out of the distribution process are analyzed one by one.

4.3.1 Trolley distribution

All flowers within the company are transported on trolleys owned by the company. A picture of a trolley is shown in Appendix H, **Error! Reference source not found.** (**Error! Bookmark not defined.**). Trolleys can be divided into two groups after auction. The first are trolleys of which the content is bought by more than one buyer, these trolleys are called 'Meerkoop' (multiple buy). An example is a trolley with 40 casks with all the same flowers. From this trolley buyer A and B buy 15 and buyer C 10 casks. This trolley has to go to the distribution area in order to get these transactions to the corresponding buyers. In contrast to the 'Meerkoop' trolleys there are 'Eenkoop' (one buy) trolleys. The content of these trolleys is bought by a single buyer and does not have to enter the distribution area, but can be delivered directly to the customer.

The distribution process described and analyzed above is only for 'Meerkoop' trolleys, this means the data used to analyze this process is from 'Meerkoop' trolleys only. In order to get an insight in the number of transactions per trolley a histogram is made for every day out of the dataset. In this analysis the frequency of every possible number of transactions per trolley is shown. Appendix H shows the analysis for every day of the dataset. Each figure shows the frequency of the transactions per trolley with the corresponding statistical distribution. The distribution is multiplied with the total number of trolleys in order to fit into this layout. The outcomes of all the days in the set are combined to calculate an overall trolley distribution, shown in Figure 12. When looking at the figures of the individual days no big anomalies can be seen, this means a solid base for the aggregated analysis.

The characteristics of the found distribution are as follows:

$X \sim \Gamma(k, \theta) \equiv \mathrm{Gamma}(k, \theta)$ $\quad$ $X \sim \Gamma(2{,}71; 2{,}31)$

Mean: $\mathrm{E}[X] = k\theta$ $\quad$ $\mathrm{E}[X] =$ [redacted] $\quad$ (1)

Variance: $\mathrm{Var}[X] = k\theta^2$ $\quad$ $\mathrm{Var}[X] =$ [redacted]

X is a random variable which represents the number or transactions per trolley, k and θ are the shape and scale parameters respectively. Concluding from the calculations above, the average number of transactions per trolley is [redacted], which results in [redacted] transactions in real life since this can only be a round number in practice.
The number of transactions has influence on the distribution time of a trolley. When there are more transactions on a trolley, the distribution worker needs more time to distribute the trolley. This relation will be discussed in the following section.

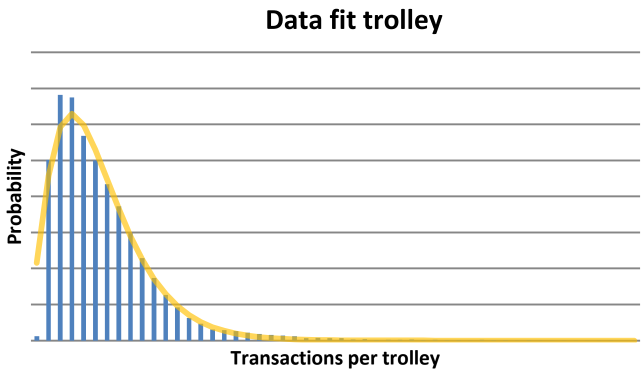

Figure 12: Transactions per trolley distribution fit

Goodness of fit
The distribution fit is conducted using the Input Analyzer from Arena, like the fitting of the arrival and processing distribution in the first part of the analysis. The first fit in Appendix H also shows the graphical and distribution summary output.
Like with the processing distribution fits the statistical tests are not sufficient, due to the large number of data points. Altiok & Melamed (2007) look at the Square Error in this case. It provides an important measure, e^2, of the goodness-of-fit of a distribution to an empirical data set, defined by

$$e^2 = \sum_{j=1}^{J} [\hat{p}_j - p_j]^2, \tag{2}$$

Where J is the number of cells in the empirical histogram, $\hat{p}_j$ is the relative frequency of the j-th cell in the empirical histogram, and p_j is the fitted distribution's (theoretical) probability of the corresponding interval. The square errors for the single days are shown next to the figure in Appendix H. The square error of the aggregated trolley distribution is 0.002069.

4.3.2 Handling time

The trolleys with more than one transaction (Meerkoop) go into the distribution area after auctioning, as described above. These trolleys are loaded into a buffer from which the distribution workers can pick them. Trolleys are taken from the buffer by a distribution worker and processed in the distribution area. A layout with a possible distribution pattern is shown in Appendix I. It is assumed the handling time of a trolley depends on the number of transactions per trolley.
The handling time of trolley is build up out of a base time, driving between locations and the time it takes to transfer the casks between trolleys. The base time is the average time it takes to make a round trip through the distribution area without accessing any lanes.
The starting point for determining the handling time is the average handling time per trolley combined with the average number of transactions per trolley. The average handling time per trolley is 8 minutes, according to the distribution department. Subsequently a sample survey is conducted to determine the base time and driving time between locations. The transfer time is deducted from these results. The measurements are shown in Appendix J. The time per transaction is calculated as follows:

$$Time\ per\ transaction = \frac{Average\ handling\ time\ per\ trolley - base\ time}{Average\ number\ of\ transactions\ per\ trolley} \tag{3}$$

$$Time\ per\ transaction = \frac{8-2}{6} = 1 \tag{4}$$

The time per transaction can be divided in driving between locations and transfer time. The transfer time is measured whit which the driving time can be calculated. All times are shown in Table 2.

Table 2: Handling times

Base time	[redacted]
Transfer time	[redacted]
Driving time	[redacted]

In this analysis the handling time is assumed to be linear, the handling time increases with one minute when the number of purchases on the trolley is increased with one. The handling time starts with a base time of two minutes as described above. However, when the number of purchases on a trolley becomes high, the distribution time does not follow this pattern anymore. Firstly since the number of purchases increases on a trolley, the volume per purchases decreases. With large number of purchases on a trolley, a distribution worker needs less time transferring the purchase to a customer trolley. Secondly, when the number of transactions on a trolley is high the chance of having stops in the same aisle also increases. When the following stop is in the same lane as the current one the worker needs less driving time, because he does not have to drive in and out lanes.
The assumption is made that at 12 purchases per trolley the slope of the handling time graph changes from 1 minute to 0.5 minute. The distribution area show in Appendix I consists of 23 aisles. The changing point of handling time is therefore assumed to be at 12 purchases per trolley. This is the first amount with which the number of purchases is more than halve the number of aisle. This increases the chance of having stops in the same aisle, which cause the total handling time to decrease. The behavior of the handling time is shown in Figure 13. This figure also shows the handling time without the adjustment for large numbers of transactions per trolley.

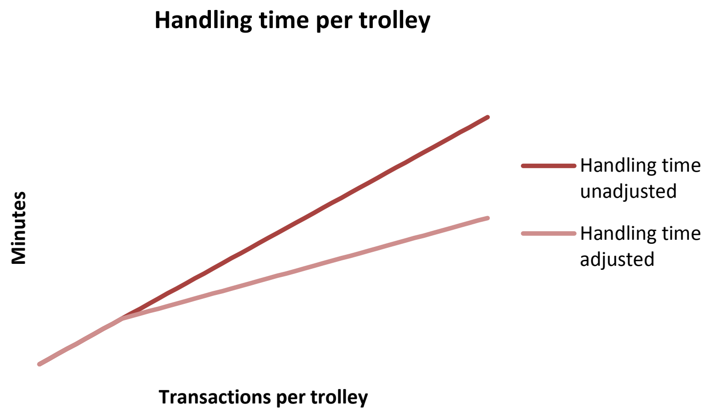

Figure 13: Handling time per trolley

4.3.3 Buyer size

The company serves a wide variety of buyers, all with its own characteristics. An important parameter is the volume of the purchased set of flowers per buyer. Since there is a wide variety among the buyers, the volume also differs a lot between them. Some clients buying flowers at the company need these flowers only for their own flower store, other act as wholesaler or exporter. In this case the amount of flowers wanted by a buyer is much higher. To get an insight in the distribution the volume per buyer on 27-09-2011 is shown in Figure 14. It is clear there is a big difference in the buying behavior of the buyers. In Appendix K the bought volume per client is shown for all days from the dataset. A persistent pattern in buyer behavior can be observed over the different days.

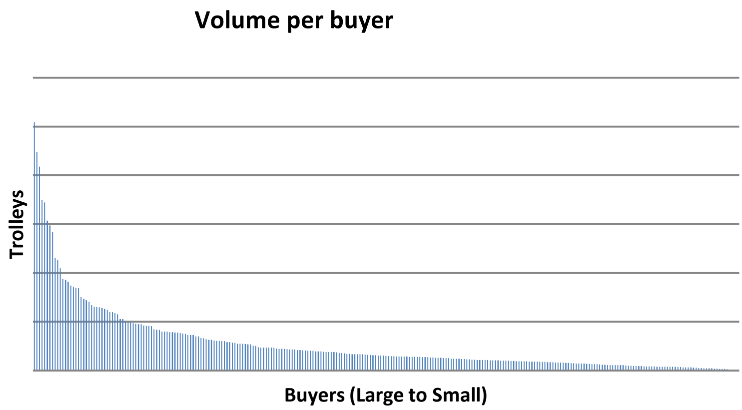

Figure 14: Buyer size

To incorporate the buyer behavior in the simulation model three types of buyers are defined, i.e. large buyers, Medium buyers and Small buyers. Large buyers purchase a volume of more than 15 trolleys, medium buyers a volume between 5 and 15 trolleys and small buyers are defined to buy less than 5 trolleys of volume. The average results are shown in Table 3 and the calculations for each day of the dataset are shown in Appendix K.

Table 3: Buyer size (3 types of buyers)

Buyer type	Trolleys per day	Hour per trolley	Trolleys per hour	Waiting time	Probability
Small	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Medium	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Large	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The objective of calculating a customer volume is to determine the output rate of full customer trolleys. However, these customer trolleys are not uniformly filled with the same casks. Customer trolleys contain different types of flowers in different casks, which means the trolley cannot be totally filled. The calculated volumes showed in Figure 14 (23) and Appendix K contain a correction factor to deal with this phenomena. In this case a correction factor of 0.9 is assumed, which means 10 percent of the customer trolleys is assumed empty. The second assumption made in this section is about the supplied trolleys, the trolleys coming from the growers. It is assumed all supplied trolleys are full.
The purchasing behavior of a buyer determines how long a single purchase is waiting on the customer trolley in the distribution area. A trolley of a buyer with a big purchasing volume will be filled faster compared to a buyer with a medium or small purchasing volume. The average waiting time for a single purchase on a customer trolley in the distribution area is shown in Table 3. This average waiting time is linked to a probability based on the number of buyers belonging to one of the three groups.
The expected value of the trolley output is $\mathrm{E}[X] = 9.6$ minutes. Calculations can be found in Appendix K final table.

4.3.4 IAT 4 characteristics

In this section an analysis is made about several important parameters regarding the IAT 4 flows.
The first point of interest is whether a trolley contains IAT 4 purchases or not. The outcome of this parameter is binary, so the amount of IAT 4 or regular purchases per trolley is not assessed in this

parameter. The analysis outcome is shown in Appendix L, the average outcome is shown in Table 4. The standard deviation is calculated with the 'n-1' method also shown in Appendix L. This is the standard deviation of the average fraction of trolleys with IAT 4 for each individual day of the dataset compared to the overall average show in the table.

Table 4: Fraction trolleys with IAT 4

Average fraction of trolleys with IAT 4	[redacted]
St. Dev. of fraction	[redacted]

Now the fraction of trolleys containing at least one IAT 4 purchase is known, the next step is to determine the average volume of IAT 4 per trolley. Of course this only concerns the 79.68 percent of trolleys which contains one or more IAT 4 purchases. Appendix L shows the result of the IAT 4 volume per trolley and Table 5 shows the average fraction of IAT 4 per trolley. Again the standard deviation is calculated using the 'n-1' method. There is a small part of the trolleys which contain only IAT 4 purchases, these are left out of the analysis. These trolleys will need a special treatment, which is no part of the main process.

Table 5: Fraction of IAT 4 per trolley

Average volume IAT 4	[redacted]
Stdev	[redacted]
Trolleys with only IAT 4	[redacted]

Next to the volume of the IAT 4 purchases per trolley the behavior of this volume needs to be analyzed. This means the number of different locations on a trolley. When a trolley contains a certain number of IAT 4 purchases, it is possible they are all destined for one location or multiple locations. The analysis of this parameter is shown in Appendix M for the whole dataset. The average distribution of IAT 4 per trolley is shown in Table 6.

Table 6: distribution IAT 4 per trolley

Number of IAT 4 locations	Average Fraction of trolley with IAT 4	Average Fraction of trolley with IAT 4 (Rounded)	Stdev
1	[redacted]	[redacted]	[redacted]
2	[redacted]	[redacted]	[redacted]
3	[redacted]	[redacted]	[redacted]
4	[redacted]	[redacted]	[redacted]
5	[redacted]	[redacted]	[redacted]
Only IAT 4	[redacted]	[redacted]	[redacted]

4.3.5 Process statistics

The distribution process is facilitated by the distribution workers. Every day a group of workers start at 6 am and work until all 'Meerkoop' trolleys of the day are distributed. This workforce can be seen as the capacity of the process. Table 7 shows the effective workers for the single days and the resulting average. This number represents the effective workers, which means the capacity of the workforce expressed in total process time shifts. In real life some workers only work parts of the process and consequently the effective workers are less than the actual amount of workers. The average number of workers for the dataset is 166.

Table 7: Effective workers

Date	Effective workers
27-9-2011	[redacted]
6-12-2011	[redacted]
7-2-2012	[redacted]
17-4-2012	[redacted]
10-5-2012	[redacted]

26-6-2012	[redacted]
	[redacted]

The distribution process starts at 6 AM every day; the end time however is variable. It depends on the number of trolleys auctioned, the complexity of the trolleys and the work rate of the distribution workforce. The average end time of the auction process for this dataset is 9:10 and the average number of auctioned trolleys is 3835 (Appendix K).

The last process statistic is the total number of transactions. In this number the transactions of all auction clocks for flowers at [redacted] for a particular day are combined. The transaction numbers for the days of the dataset are shown in Table 8 as well as the average number of transactions.

Table 8: Number of transactions per day

Date	Number of transactions
27-9-2011	[redacted]
6-12-2011	[redacted]
7-2-2012	[redacted]
17-4-2012	[redacted]
10-5-2012	[redacted]
26-6-2012	[redacted]
Average	[redacted]

The number of transactions shown in Table 8 are the combined transactions made at the 8 flower auction clocks at [redacted]. The transactions are assumed to become available immediately after auctioning in a uniform way. Difference in distance from auction room or cooling cell to distribution area is neglected.

5 Directions for redesign

In the previous section an extensive analysis is conducted about the distribution process at [redacted]. The results and conclusions from this analysis can be used to formulate and analyze possible new situations. The following part of the project will be about constructing a new possible situation or redesign to improve the existing situation. In this chapter the possible redesigns will be assessed one at a time.
Before describing the possible directions for redesign, the current situation will be discussed again shortly. After the trolleys are auctioned, they enter the buffer. Distribution workers take a trolley out of the buffer and transfer all purchases to the trolleys of the buyers. The purchases then wait on the customer trolley until this trolley is full. Full trolleys are then delivered to the boxes of the buyers.

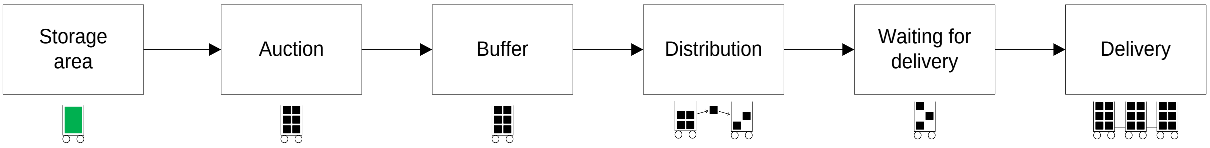

Figure 15: Current distribution process

5.1 Release IAT 4 before distribution

The first possible situation is the extraction of the IAT 4 flows from the trolleys before distributing them. In this option, already loosely explained in the research proposal (Roebroek, 2012), all purchases with an external destination will be taken from the trolley and fed into the distribution process at the location of the buyer. The conceptual model is shown in Figure 16 (28).
After the flowers are auctioned the trolleys go into the buffer like in the current situation. When a distribution worker takes a trolley out of the buffer, the voice system first tells whether the trolley contains an IAT 4 purchase or not. When this is not the case the trolley will be distributed the normal way, like in the current situation. When the trolley does contain an IAT 4 purchase, or multiple, the distribution worker will drive to a designated area where the IAT 4 purchases will be taken from the trolley. The trolleys on which these purchases are loaded are not linked to a customer, only to a location. For every external location of the company an aisle or multiple aisles will be reserved, in order to make the release of IAT 4 purchases process as smooth as possible. These aisles will be connected with docks close by, so the full trolleys can be loaded in to trucks as quickly as possible. Within every aisle a distinction will be made between different cask codes (fustcodes). The outgoing trolleys are filled with only one type of cask, which results in the most optimal load factor possible. In addition to this load system package units which are very rare will be put together on a trolley to ensure low wait times in the distribution area.
When all IAT 4 purchases are of the trolley it will be distributed like in the current situation. At a certain point in time all locations in the network will receive trolleys from other locations, containing IAT 4 purchases destined for this location. This point in time depends on the loading, unloading and transportation, in Figure 16 denoted as process C. The incoming trolleys will be fed into the buffer of the distribution process and subsequently distributed in the standard way. With these trolleys there is no concern to look for IAT 4 purchases because the entire content of the trolley is for local customers.

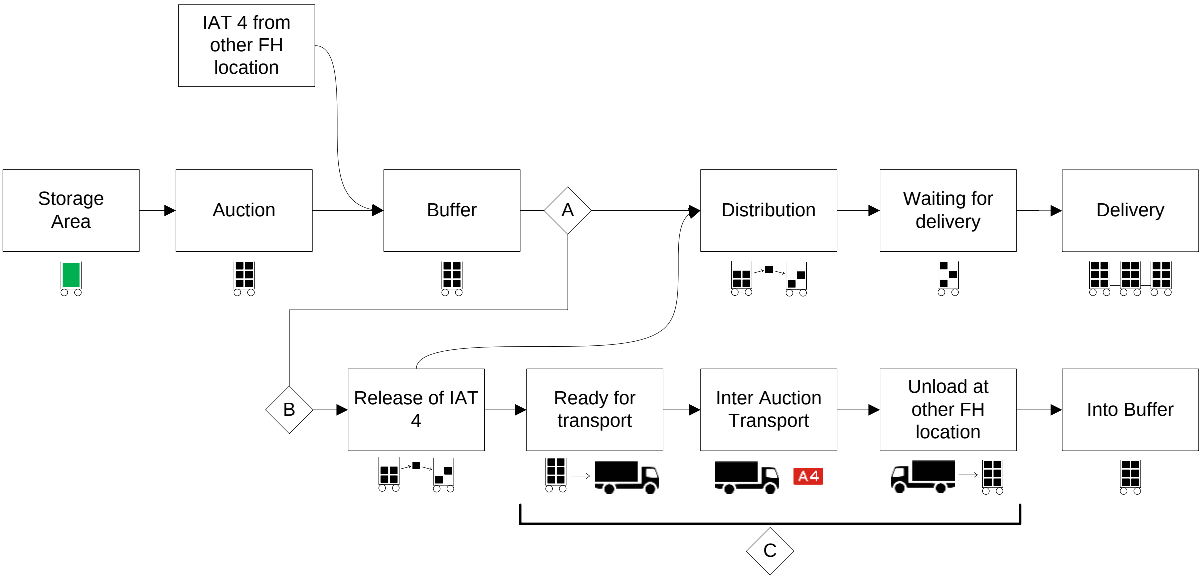

Figure 16: Release IAT 4 before distribution

5.2 Release IAT 4 after distribution

The second redesign is not as radical as the first redesign. In this situation the trolleys taken from the buffer will be distributed like in the current situation. However, customers from another location are grouped in the same aisle. In this configuration the first aisle will contain only buyers from [redacted], the second aisle only buyers from [redacted] and so on. The remaining aisles will stay as they are now configured. The same as in the previous redesign the aisle linked to another location are connected to docks where the trolleys, in this case related to buyers, can be loaded into trucks.
To unload the trolleys a new process has to be constructed. The trolleys have to be distributed to the boxes of the customers, which is currently done by making long trains in which boxes close to each other are combined. The trolleys coming from the trucks have to be sorted and then grouped into trains to be delivered at the right boxes.

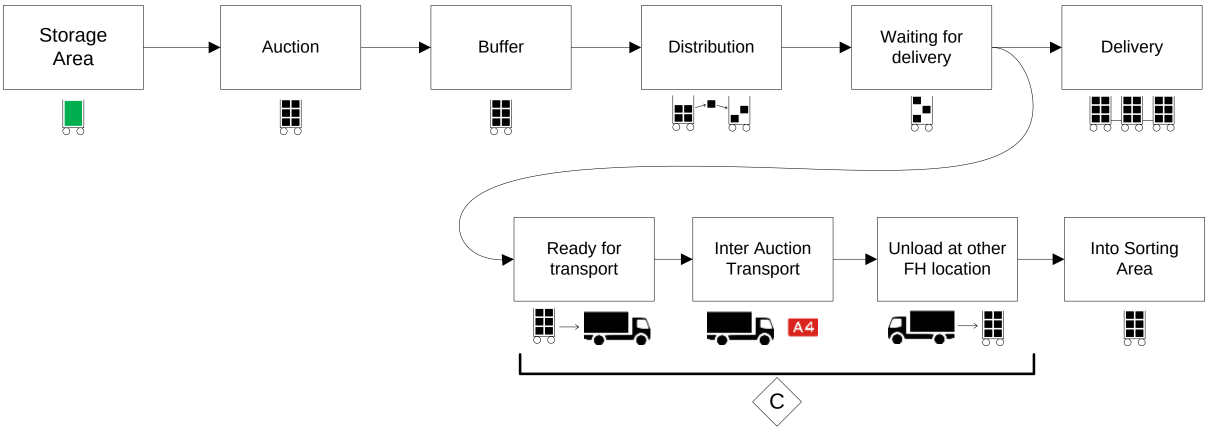

Figure 17: Release IAT 4 after distribution

5.3 Radical change of distribution landscape

In this section two redesigns are proposed, which are expected to result in radical changes of the current processes of the company. The previous redesigns are constructed with the current processes of auctioning, distribution and delivery in mind. It might however be beneficial to assess the problem without thinking about the current processes.

5.3.1 Buy size equal to handling size

In this redesign the volume a buyer has to purchase is equal to the volume in which the flowers are handled by rule. Since the flowers within the company are transported on trolleys, these can be seen as the handling size. Because this project is looking at the IAT 4 flows, buyers are obligated to buy only full trolleys when it concerns a IAT 4 purchase. When a buyer is situated in the same location as the purchase, he can buy as in the current situation. In this concept the trolleys headed for another location can be split from the process before the buffer. The concept is shown in Figure 18.

This process redesign can induce resistance from the buyers, because they are restricted in their buying behavior. However the change will reduce the delivery time and cost of IAT 4 purchases compared to the current situation.

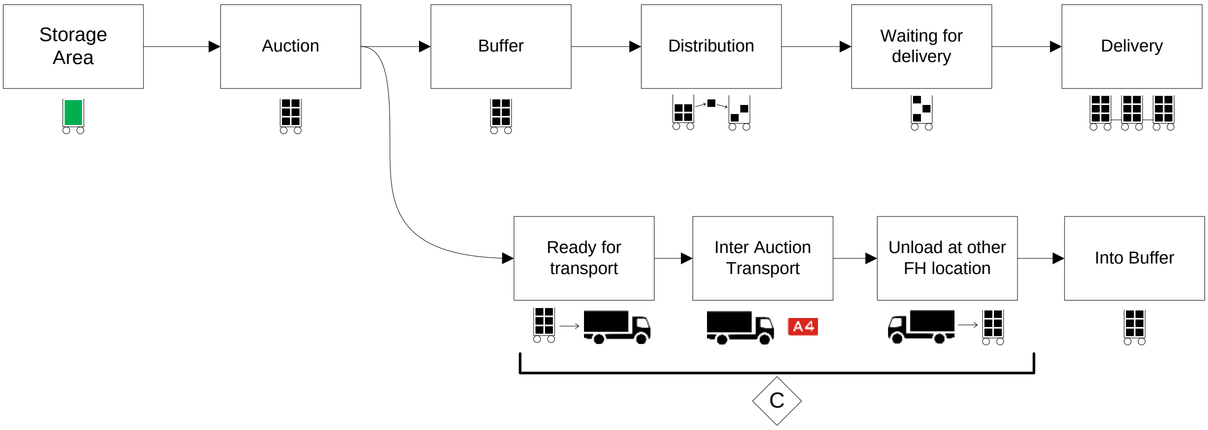

Figure 18: Buy size equal to handling size

5.3.2 Virtual supply and Cross docking

A second option for redesign which is out of the box is shown in one which uses virtual supply and cross docking, shown in Figure 19. In this scenario growers keep their products physically in house and only supply information of what they have to offer. The flowers are then auctioned without being present at the auction. Directly after auctioning and when the destination for the products is known, the flowers are transported to the corresponding auction sight. The trolleys are then distributed and delivered at the customers. Buyers which do not have a box in a company location will be served using cross docking, discussed in the literature review. This way products do not enter the facility when their destination is outside the network.

This option reduces the repositioning of products and consequently reduces the total distance covered by the products in the network. However, this option will change the processes dramatically and will ask cooperation of both growers and buyers.

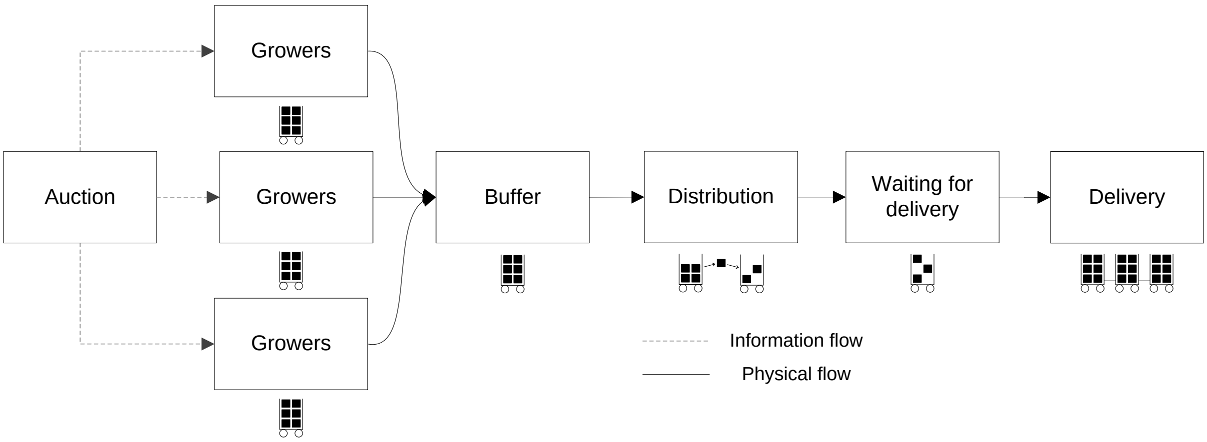

Figure 19: Virtual supply and cross docking

5.4 Conclusion redesign direction

This section discussed several possibilities for redesign. Some of them are a relative small change to the current situation. Other options are more radical and ask for a big change in the floriculture landscape. Because of the requirements outspoken by the company and the higher expectation of feasibility the first redesign is chosen to be further analyzed. In the trail of this redesign and its analysis the second redesign will also be assessed. These redesign options are constructed in close collaboration with the company.

However the first redesign, and in lesser extent the second redesign, are chosen for analysis does not mean the other directions for redesign have to be discarded. Currently they are probably not feasible but maybe in the future they are. In addition, changes of this magnitude need enough support from the organization. Nonetheless they might provide a long term view of how the floriculture landscape should look then. It can also be used to implement parts of them or altered versions may be a better option. Therefore it might be valuable to conduct these researches in the future.

6 Redesign

In this section the redesign will be outlined. First the concept of simulation will be shortly addressed. Subsequently the base model and redesign model will be described.

6.1 Concept of simulation

Before one begins with analyzing a redesign using simulation, the question has to be asked whether it is necessary to use simulation. It might be possible there are several other ways to assess the problem. To determine this necessity, the decision tree shown in Appendix N, Figure 37 (74) is used. When other options are available to answer the problem, this might be a better option than simulation. Mathematical models which provide an exact or approximate solution for the problem and is easier to check in most cases.
However, due to the uniqueness of the process and especially of the redesign settings, simulation seems to be an appropriate way to answer the research questions.

6.1.1 Model Verification and Validation

This chapter focuses on goodness assessment, and specifically on its two components: *verification* and *validation*. Verification assesses the correctness of the formal representation of the intended model, by inspecting computer codes or test runs, and performing consistency checks on their statistics. Validation assesses how realistic the modeling assumptions are, by comparing model performance metrics (predictions), obtained from model test runs, to their counterparts in the system under study. This is possible in the case of this project, but in case of no existing process this is not possible. (Altiok & Melamed, Simulation modeling and analysis with Arena, 2007)

Verification

Verification consists in the main of the following activities:

- Inspecting simulation program logic
- Performing simulation test runs and inspecting sample path trajectories.
- Performing simple consistency checks, including sanity checks (quick “back-of-the-envelope” plausibility checks), as well as more sophisticated checks of theoretical relationships among predicted statistics.

Note carefully that *absence of evidence is not evidence of absence*. Thus, verification and validation are best-effort activities that conclude when the analysis is reasonably sure of model goodness; however, the true state of “correctness” is rarely known conclusively (Altiok & Melamed, Simulation Modeling and Analysis with Arena, 2007).

6.1.2 Number of replications

Due to the very nature of random numbers, it is imprudent to draw conclusions from a model based on the results generated by a single model run. Replication is defined as executing the same model a number of times, but with different random numbers in each run. As a rule of thumb, a modeler should always perform at least three to five replications for each experiment (Mehta A. , 2000).
Following this rule of thumb for all experiments five replications will be performed. The averages of these replications will be used to calculate, compare different scenarios and draw conclusions. A graphical representation of the experiments and its replications is shown in Appendix N.

6.1.3 Warm up period

In the analysis section the concept of warm up period is discussed for the real life situation of the distribution process. From the data at hand it is concluded the distribution process at [redacted] has no significant warm up period. However, for the simulation models this has to be assessed again in order to make accurate calculations with the output data of the simulation models. The output generated in the warm up period will not be used in the calculations, because at this moment of time the system has not yet reached a steady state. Only output from this phase can be used for calculations.

6.2 Base Model

The starting point for the redesign is building a simulation of the current situation. Figure 15 (27) shows the conceptual model as described in the previous section. The first objective is to translate this model and its component in a simulation model. In this section each section of the simulation will be zoomed in on and explained.

Arrival

Entities are created based on a constant inter arrival time, and represent a trolley coming from the auction. As explained in the analysis in real life the trolleys move over a chain conveyor with constant speed. The inter arrival time is [redacted] seconds, which comes down to roughly [redacted] trolleys per minute. It is assumed trolleys come available for distribution directly after creation.

The arrival process stops after having created [redacted] entities. This is the average number of trolleys auctioned based on the dataset. The stopping of the arrival process also preludes the end of the process. When there are no more entities created the systems runs empty which is the end of the simulation. By keeping the number of entities constant, the different experiments can be easily compared.

Before coming available for distribution, every entity receives an attribute. This attribute can be seen as a little back pack in which the entity can store information. The information stored in this attribute is the 'trolley distribution'. This concept explained in section 4.3.1, resembles the number of transactions on the trolley. This number is a random variable X with $X \sim \Gamma($[redacted]$)$, which means X is Gamma distributed with shape parameter [redacted] and scale parameter [redacted]. The value generated by this distribution for every attribute is rounded to the nearest integer.

Distribution Process

The simulated process has one type of resource at its disposal. This type of resource models the distribution worker. For the base model [redacted] resources are available based on the average number of distribution workers in the dataset. Each entity requires one resource to go through the process and each resource can handle one entity at a time. As soon as an entity leaves the process, the resource is available again.

The time an entity spends in the process depends on the attribute it received in the previous section. This process time is explained in section 4.3.2. The process time depends on the value of the attribute of the entity as shown in Figure 13 (22).

When an entity, representing a trolley, leaves the process it releases its resource, which is now available again for the entities in the queue. After the resource is released, the entity is split into transactions. This means from this point on forward an entity no longer represents a trolley but a purchase made by a buyer. The entity is split into a variable number of entities; this is again based on the attribute representing the number of transactions on a trolley. The initial entity, representing the trolley, leaves the system after its data is recorded in the data file.

Wait time buyer trolley

In this section of the model an entity no longer represents a trolley but a transaction. The transaction is transferred from the auction trolley to the customer trolley in the previous section. The time this entity has to spend on the buyer trolley depends on the buyer size distribution as explained in section 4.3.3. After the entities are created by splitting the original trolley entity it gets again an attribute. This attribute contains the wait time based on the buyer size distribution. The entity then fulfills this wait time and writes its data to the date file before leaving the simulation.

6.2.1 Mapping conceptual model to Arena

Table 9 shows the mapping of the conceptual model to the Arena process model. This mapping creates a link between the conceptual model, shown in Figure 15 (27), and the Arena simulation model. Each process step in the conceptual model is translated into the representing parts in the simulation model. It is not always possible to translate every process step exactly to a process in the Arena model. However, this gives a good insight in the constructs of the simulation model. In this project Arena is the simulation software of choice, due to availability and prior knowledge of the modeler. However, other simulation software programs can also be used to simulate the desired process. The simulation model of the current situation is shown in Appendix O.

Table 9: Mapping conceptual model to the Arena process model – Base model

Conceptual model	Arena	Function
Storage area	Out of scope	
Auction	Auction (Create)	Create trolley entities with a Const([redacted]) distributed inter arrival time (time in seconds) Create is terminated at [redacted] trolley entities created.
Buffer + Distribution	Assign 1 (assign) Seize 1 (seize) Decide 1 (decide) Distribution (process) Distribution long (process)	Gives trolley entity attribute with number of purchases (Gamm([redacted]) Create queue and use resource for distribution or distribution long based on decide [redacted])
Waiting for delivery	Transit between trolleys (separate) Assign 2 (assign) Waiting on buyer trolley (delay)	Separate trolley entities in purchase entities Delay purchase base on DISC([redacted]) distribution
Delivery	Go into LDK (dispose)	Entities leave the model and information is stored

6.3 Release IAT 4 before distribution – Redesign

Now the base model is translated in a simulation study, the redesign can be modeled for simulation. The redesign option which will be analysed using simulation analysis is the Release of IAT 4 before distribution as discussed in chapter 5; the conceptual model of the redesign is shown in Figure 16 (28).
The starting point for the model is the construction of a black box in order to get in insight in the input variables and output variables.
To simulate the system we need input variables. There are two types of input variables:

- Environmental variables: Variables we can't modify and that are a result of the environment of the system.
- Control variables: Variables we can control or change.

Analytical techniques or simulation studies will use the values assumed by these variables to produce output variables that will allow answering questions about the performance of the system (Goossenaerts & Pels, 2010).

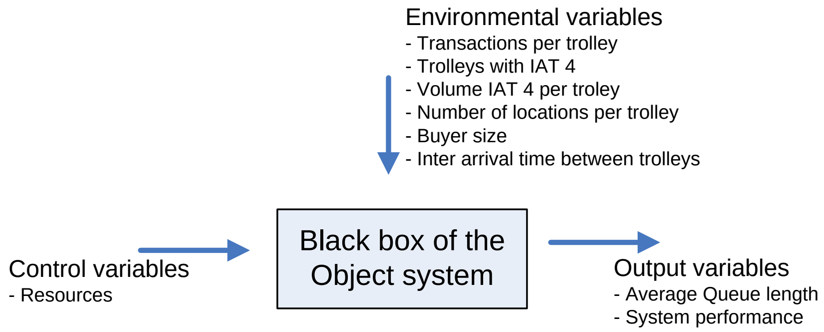

Figure 20: Black box with variables

Just like the previous section where the base model is assessed, this section provides an explanation of each section of the simulation model of the redesign. Some parts of the model will not be explained to the full extend, because they are the same as in the base model. New features and processes will get more attention.

Arrival

The arrival process of the redesign is the same as the base model. The auction process is not changed in the situation of the redesign, because the auction process is not changed in the redesign. This means the trolley distribution (number of transactions per trolley) also remains the same in the redesign. Entities receive an attribute containing this stochastic value. Subsequently an entity takes a resource, which enables it to enter the process.

Sub process for IAT 4

Entities enter this part of the process based on a two way by chance. This is based on the chance a trolley contains one or more IAT 4 transactions, which is determined in chapter 4. [redacted] per cent of the entities enter the sub process. Upon entering the entity receives another attribute, next to the trolley distribution attribute. This new attribute states if the IAT 4 on the trolley has to go to one external location or more. The variable equals the number of locations. After receiving this attribute the entity goes through the release of IAT 4 process. This process time is based on the IAT 4 attribute, which is [redacted] seconds for each location (transferring and leaving lane). This time is shorter than for normal transactions, this is because the IAT 4 lanes are right next to each other. The variable time is augmented with [redacted] seconds, which is the time for driving from the buffer to the first lane (Appendix J). After completing the release of IAT 4 process the trolley entity is split into the original entity and new entities for each IAT 4 transaction. The new entities will enter the inter auction transport process, which will be discussed later. The original entity proceeds into the distribution process.

Distribution process

The distribution process is the same as the base model, except for one thing. Trolleys coming from the sub process for IAT 4 have different process characteristics. The attribute containing the trolley distribution is updated between the sub process for IAT 4 and distribution process. The attribute variable is reduced with [redacted] per cent based on the analysis section 4.3.4. This results in a shorter distribution time for entities coming from the sub process for IAT 4.

[redacted] per cent of the entities enter the distribution process directly after arrival. These entities follow the same process as the entities in the distribution process of the base model. It is important to mention that all entities in all processes pick a resource from the same set. In other words, there is a single uniform workforce for the total process.

Inter auction transport
Entities coming from the release of IAT 4 sub process are of two types. The first type of entities represents the trolleys of which IAT4 transactions are taken. The second type of entities coming from the release of IAT 4 sub process represents the transactions coming from the trolleys in the sub process. The second type of entities enter the inter auction transport section. The first item does not, but enters the distribution process as described above.
The entities entering this part of the model first spend 90 minutes in the inter auction transport process. No resource is needed in this process, it is assumed the number of docks and trucks is always sufficient to handle the flows coming out of the system. The [redacted] minutes consist of [redacted] minutes loading, [redacted] minutes transporting and 10 minutes for unloading. The entities coming out this process become the input for the incoming IAT 4 purchases. Since the same process is used at the other locations of the company, also an incoming flow of IAT 4 product arises.
For the incoming flow several assumptions are made. The incoming flow of IAT 4 coming from the other locations is a product of the outgoing flow. The flows are based on the volumes handled by every location of the company. The volume of the sight at [redacted] is declared as one and consequently the volume of [redacted] is assumed [redacted] and the volume of [redacted] is assumed [redacted]. The other locations are not taken into consideration, because of their small sizes. Following this assumptions, the incoming flow of IAT 4 is twice as big as the outgoing flow. Entities coming out the inter auction transport are merged again to resemble trolleys (merged at average trolley size – [redacted]). Subsequently the entities are multiplied by two and fed into the queue of the distribution process. The entities enter directly into the distribution process described above.

6.3.1 Model scenarios
The redesign model can be divided into two scenarios each with their own characteristics and outcomes. In the first scenario, the incoming IAT 4 products are hold from entering the queue of the distribution process until all auctioned trolleys are in the queue. When the arrival process stops the IAT 4 purchases are released en enter the queue of the distribution process. In the second scenario the incoming IAT 4 purchases are fed directly into the queue of the distribution process. This results in a mix of trolleys coming from the auction process and trolleys containing incoming IAT 4 in the queue and consequently also in the process. The behaviour of both scenarios will be discussed later on.

6.3.2 Mapping conceptual model to Arena
Like with the base model, a translation is made between the components of the conceptual model, shown in Figure 16 (28), and the simulation model. It is an addition on the model explanation described above, the function explanation is added for clarity

Table 10: Mapping conceptual model to the Arena process model – Release IAT 4 before distribution

Conceptual model	Arena	Function
Storage area	Out of scope	
Auction	Auction (Create)	Create trolley entities with a Const([redacted]) distributed inter arrival time (time in seconds) Create is terminated at [redacted] trolley entities created.
Buffer	Seize 1 (seize) Seize 2 (seize)	Queues are built by seizing same resource
Bifurcation point A	No IAT 4 on trolley? (decide)	Splits entities with or without IAT 4 purchases (Two way by chance [redacted]%)
Bifurcation point B + Release of IAT 4	Seize 1 (seize) Assign 3 (assign)	Entity gets attribute with number of location based on DISC([redacted]

	Release IAT 4 (process) Separate 5 (separate 5)	[redacted]) Create queue and use resource for release of IAT 4 Split entity in existing entity and transaction with external destination
Ready for transport + Inter auction transport + Unload at other location	Process 8 (process)	Transactions are delayed [redacted] minutes (time for transportation)
Into buffer + IAT 4 from other location	Batch 5 (batch) Assign 5 (assign) Hold 2 (hold) *-Optional-* Seize 2 (seize)	Transactions are batched by [redacted] (incoming volume= outgoing volume * 2) and receive attribute with number of transactions per trolley Transactions have to wait for end distribution process (optional) Entities seizes distribution resource
Distribution	Assign 2 (assign) Seize 1 (seize) Decide 5 (decide) Decide 6 (decide) Dist. Normal (process) Dist. Normal Long (process) Dist. After IAT 4 (process) Dist. After IAT 4 Long (process)	Gives trolley entity attribute with number of purchases (Gamm([redacted]) Create queue and use resource for distribution or distribution long based on decide (<12) Trolleys with IAT 4 released use distribution process for smaller volume
Waiting for delivery	Separate 1 (separate) Separate 6 (separate) Assign 4 (assign) Wait on customer trolley (process)	Separate trolley entities in purchase entities Delay purchase base on DISC([redacted]) distribution
Delivery	Dispose 1 (dispose) Dispose 2 (dispose) Dispose 3 (dispose)	Entities leave the model and information is stored

7 Discussion of simulation results

In this section the results from the simulation models described in the previous section will be evaluated. First the results of the base model are assessed, which in itself will act as input for the further analysis of the redesign simulation output. Before using the result of the base model as input for the redesign, the initial results from the redesign will be reviewed.

7.1 Output base model

The base model is run with the parameters as described in Table 9 (33). Figure 21 and Figure 22 (38) show the graphical output of the base model. The simulation of the base model is conducted by running 5 replications as described above. The output shown is the results from replication 3.

The model first assigns a resource (distribution worker) to an entity (trolley). This is done in the Seize module. An entity can only seize a resource if one is free; in case of no free resource the entity has to wait in the queue. Figure 21 shows the queue length of the distribution process. When an entity has a resource it goes into the distribution process. The model has two parallel processes, one for trolleys with less than 12 transactions and the other for trolleys with 12 transactions or more. The number of trolleys in this total process is shown in Figure 22 over time. This parameter is called the Work In Progress (WIP). A clear upper bound can be seen in the figure, which is equal to the number or distribution workers available for the distribution process. The number of resources is set on 166 effective workers based on the data analysis in the previous section.

The output of the other replications is shown in Appendix Q. These figures show comparable behavior, but are not exactly the same. This is the result of the use of random variables in the simulation runs as described in the sections 6.2 and 6.3.

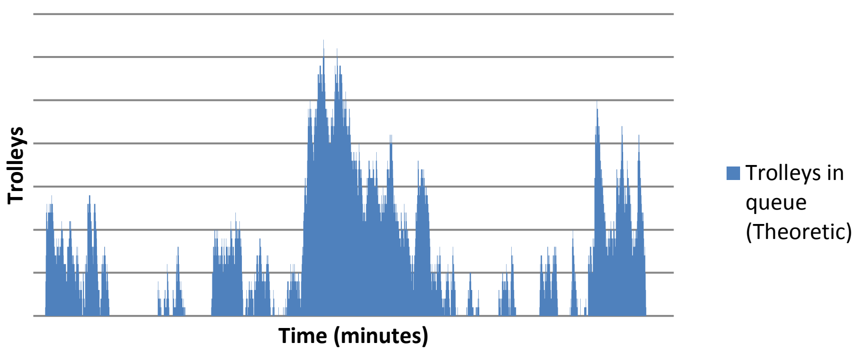

Figure 21: Queue length - base model (replication 3)

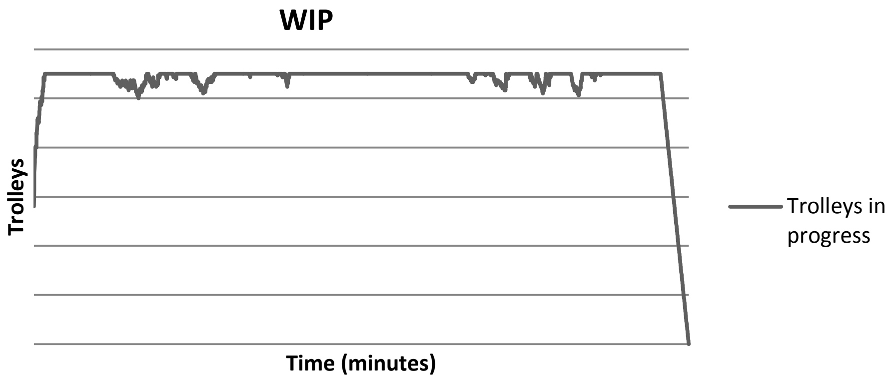

Figure 22: Work in progress - Base model (replication 3)

7.1.1 Warm up period

The concept of warm up period as described in section 4.1.3 has to be assessed for this simulation model also. In the current situation no significant warm up period could be determined from the data. However, looking at Figure 22 a transient state can be observed. This part is called the warm up period. All replications reach a steady state after 10 minutes, which means the data collection starts after 10 minutes. More clearly, the calculations are done with data past 10 minutes. This warm up period will also be used when analyzing the simulation of the redesign. This ensures consistency in the calculations and good comparisons can be made.

7.1.2 Analysis of output - Confidence interval

An important parameter of the base model is the average queue length. This parameter will be used as a benchmark for the simulation model and its analysis. Together with calculation the mean, a confidence interval for this variable will be calculated.

A (1-α)% confidence interval for the mean is a range of values running from a lower bound (LB) to an upper bound (UB) wherein we can be (1-α)% confident that the true population mean falls.

Confidence intervals for the mean when the population standard deviation is estimated form the data

$$\boldsymbol{LB} = \bar{\boldsymbol{X}} - \left(\boldsymbol{t}_{\boldsymbol{df},\alpha/2}\right)\frac{\boldsymbol{s}}{\sqrt{\boldsymbol{n}}} \qquad (5)$$

$$UB = \bar{X} + \left(t_{df,\alpha/2}\right)\frac{s}{\sqrt{n}} \qquad (6)$$

s = the standard deviation (calculated from the data) $= \sqrt{\frac{\sum_{i=1}^{n}(X_i-\bar{X})^2}{n-1}}$ (7)

n = number of replications in the simulation

$t_{df,\alpha/2}$= value from the *t-Distribution Table*,

df = ‘degrees of freedom’, a measure of how much data was available; df = n-1

Table 11: Average queue length per replication - base model

Replication	1	2	3	4	5
X_i	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

$$\bar{X} = \sum_{i=1}^{n} \frac{X_i}{n} = \frac{4{,}645 + 23{,}123 + 6{,}797 + 3{,}653 + 5{,}215}{5} = \text{[redacted]} \quad (8)$$

$$s = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}} = \text{[redacted]} \quad (9)$$

Confidence interval:

$$LB = MAX(0; \bar{X} - \left(t_{df,\alpha/2}\right)\frac{s}{\sqrt{n}} = MAX\left(0; 8{,}69 - 2{,}776 * {}^{12{,}627}/_{2}\right) = \text{[redacted]} \quad (10)$$

$$UB = \bar{X} + \left(t_{df,\alpha/2}\right)\frac{s}{\sqrt{n}} = 8{,}69 - 2{,}776 * {}^{12{,}627}/_{2} = \text{[redacted]} \quad (11)$$

CI = [[redacted]] (12)

It can be stated that with [redacted]% confidence the sample mean of the queue length of the base model falls between [redacted] and [redacted] trolleys on average.

It is important to mention that this average queue length is of theoretical nature. The actual queue length in de buffer differs from this theoretical value. However, since this theoretical queue is used consistently to assess the performance of the simulation experiments coming up, it is not a problem for the conclusion. There are several reasons for this difference. First of all the transfer from the auction room or cooling cell demands a buffer which is managed by the buffer operator. Secondly, priorities are created in the buffer which causes delays on average. Another reason for this disparity is the workforce taking breaks during the process. The workforce is divided in teams each taking a break by rotation. Also the auction process is paused at 7AM providing the buyers an opportunity to drink a cup of coffee. These variables are not incorporated in the model. However, the theoretical queue length can be used to test the redesign, because the redesign also lacks the variability's as described above.

7.1.3 Verification & Validation

When looking at the animated process no mayor problems where to be discovered. The model showed no congestions and the flows appear to be in line with each other.
The average output of transactions of the simulation model can be calculated based on the values in Table 12. These numbers resemble the number of transactions made at the auction clocks and the number of purchases going into LDK as well. The number of output is 5, which is equal to the number of replications in the simulation experiment

Table 12: System output - Base model

Replication	1	2	3	4	5	Average
System output	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

To make a comparison the data from the current distribution process is introduced as well. The average number of transactions resulting from the dataset is 25940 compared to 24200 transactions on average for the simulation model. Taking stochasticity, and the assumptions made in the model into account this is a satisfactory result regarding system throughput.

The average wait time on the buyer trolley for every transaction in the simulation model has a weak output. The average wait time in the model is much higher compared to practice. The assumptions about full supplied trolleys and the correction factor for the buyer trolley appear to have big influence on the result. However, during simulation it appeared this parameter has no influence on the analysis and the subject under investigation. Therefore this fallacy will be ignored for the rest of the simulation study. Whenever this part of the model or this parameter is used in further research it needs a thorough inspection and evaluation.

7.2 Output Redesign model

As explained in the previous section, there are two scenarios for the redesign simulation. In this section both scenarios will be analysed with the initial value for the control variable.

7.2.1 IAT 4 hold until end auction process

The first observation regarding the differences between models can be observed in this simulation run. The starting point for the redesign simulation model is running it with the same number of resources as the base model. This means the control variable is the same as the base model and consequently also the same as the average number of workers currently working in the distribution process at [redacted]. The first run in conducted using scenario 1, incoming IAT 4 hold until entity creation process is ended. The output of this experiment is shown in Figure 23, Figure 24 (41) and Figure 25 (41). This is the output from replication 1, from the total number of replications is 5.

Figure 24 and Figure 25 show Queue 1 and Queue 2. In practice there is no such thing as two queues, however for modelling reasons the simulation model shows two queues. Queue one shows the number of trolleys in the buffer coming from the auction, these are trolleys supplied at [redacted]. Queue 2 shows the number of trolleys containing IAT 4 products in the queue. For clarity, these are IAT 4 products coming from other auctions which have their exit point at [redacted]. In practice these queues form one physical queue in which local trolleys and trolleys containing IAT4 stand next to each other.

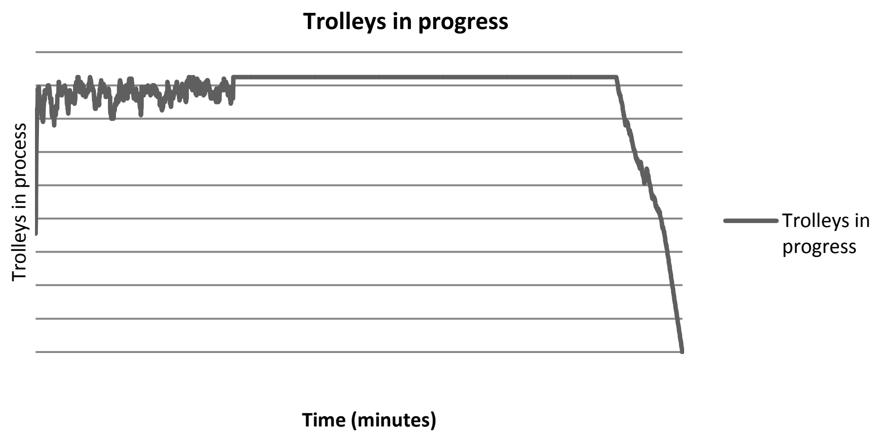

Figure 23: Work in progress – Redesign scenario 1 (replication 1)

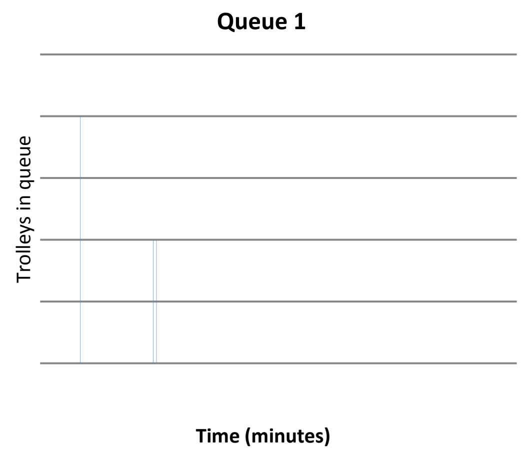

Figure 24: Queue 1 length – Redesign scenario 1 (Replication 1)

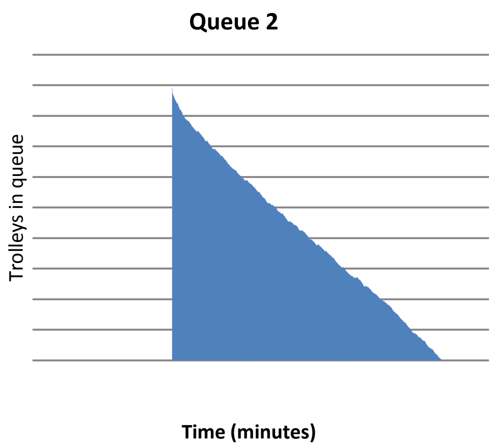

Figure 25: Queue 2 length – Redesign scenario 1 (Replication 1)

Figure 23 (40) shows the work in progress over the total time of the redesign. The first part of the graph shows the period before the IAT 4 flows coming from other auctions is allowed to enter the queue. The graph line shows that the workforce is not fully utilized for most of the time. This is in line with the behavior of the length of queue 1. Figure 25 shows the number of trolleys in the queue. The point in time at which the incoming IAT 4 is released, due to the end of the auction process, can be observed clearly.

When comparing the results from the base model and the results from the first experiment of the redesign, several differences can be observed. The most important difference is the empty queue. The output for the queue length of each replication is shown in Table 13

The average queue length and confidence interval of this experiment (Redesign, resources: [redacted], scenario 1) is calculated the same way as is done for the average queue length of the base model and shown in Table 13 and Table 14.

Table 13: Average queue length per replication – Redesign scenario 1

Replication	1	2	3	4	5
X_i	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 14: Average queue length and CI – Redesign scenario 1

$\bar{X}_i$	[redacted]	
s	[redacted]	
Confidence Interval (α=0.05)	[redacted]	[redacted]

The output of this experiment shows virtually no queue. In addition, the work in progress is lower than the available workforce during almost the total distribution of trolleys coming from the auction process. This means the occupancy of the redesign with these settings has a lower occupancy rate than the base model.

7.2.2 IAT 4 directly in distribution queue

Scenario 2 is the redesign in which incoming IAT 4 products are directly fed into the queue of the distribution process upon arrival. Again this scenario is run with the same input variable as the base model and the previous scenario. It is important to emphasize the priority rule of the queue of the

distribution process is FIFO (First Come First Served). This means an incoming IAT 4 trolley which is earlier at the queue than a trolley coming from the auction, will be handled earlier as well.
The result from the simulation is shown in Figure 26 and Figure 27.

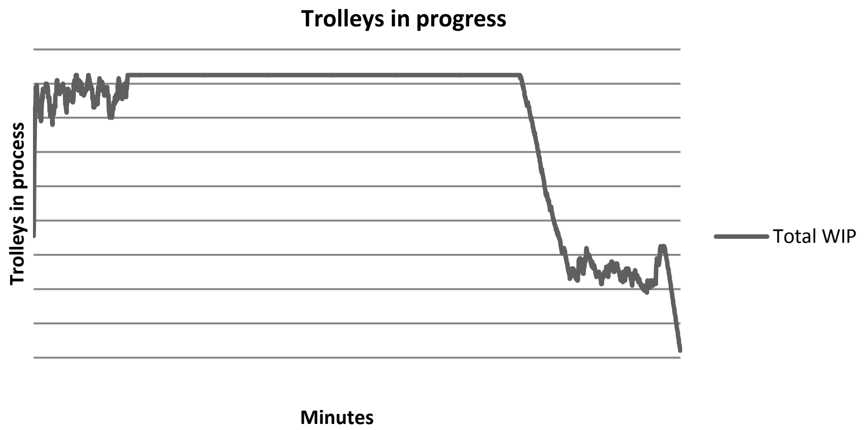

Figure 26: Work in progress – Redesign scenario 2 (replication 1)

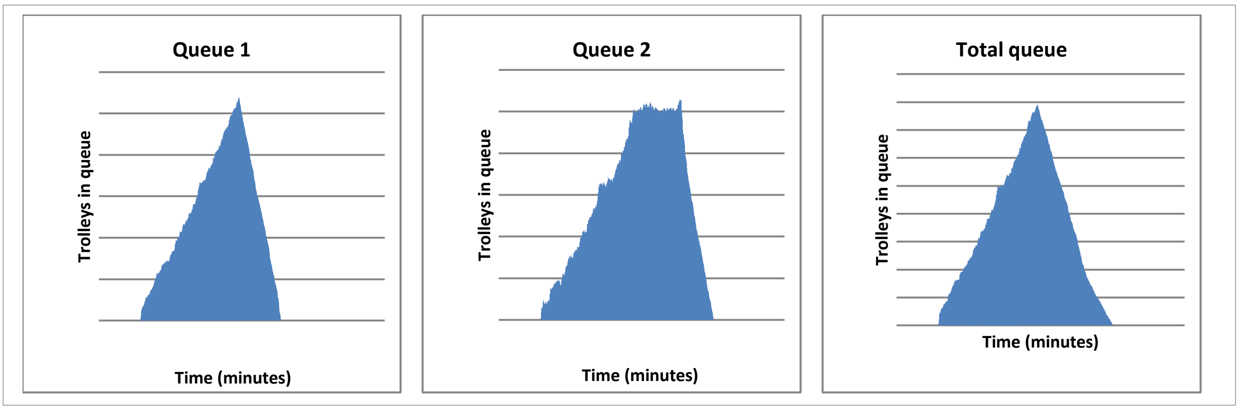

Figure 27: Queue length – Redesign scenario 2 (Replication 1)

The behavior of the two scenarios shows some big differences. The first difference is between the work in progress of both systems. Scenario 2 shows that the resources are in constant use at an earlier time. This is the result of the incoming IAT 4 entering the process before the auction process has come to an end. Secondly, at the end of the process the biggest part of the workforce is sitting idle when suddenly the WIP drops with [redacted] workers. At this moment all trolleys coming from the auction are distributed and only the incoming IAT 4 trolleys have to be handled. However, this arrival rate is much lower than the capacity of the workforce, which results in a low occupancy. The effect can also be observed in the queue figures (Figure 27). As soon as the incoming IAT 4 trolleys start to arrive, the queue builds up. Subsequently when all trolleys coming from auction are distributed, the queue runs empty and the available trolleys for the process become much less than the workforce capacity.
The average total process time of this scenario is [redacted], which is much more than the total process time of scenario 1.

Table 15: Average queue length per replication – Redesign scenario 2

Replication	1	2	3	4	5
X_i	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 16: Average queue length and CI – Redesign scenario 2

$\overline{X}_i$	[redacted]	
s	[redacted]	
Confidence Interval (α=0.05)	[redacted]	[redacted]

Since the behavior of scenario 1 is much more desirable (high occupancy and lower total process time), this scenario is used for future experiments. It is assumed that the implementation of both scenarios requires equal effort and investments. The scenarios are only examined on their performance. Scenario 2 will therefore not be taken into consideration in the future analysis.

7.2.3 Verification and validation

For the verification of the redesign model the some parts can be used from the base model can be used. When running test runs no congestions could be observed for this simulation model. The throughput and paths taken by entities is in line with the expected behaviour.
Since this is a simulation of a process which does not exists, no real life data is available to compare with the simulated system output. However, the part of the model which does exist behaves desirable according to the validation of the base model.

7.3 Sensitivity analysis

The objective of this simulation study is to find the new size of the workforce. Since the redesign showed low occupancy with the initial input variable, it is expected that the workforce can be reduced in the redesign and still have the same performance as the base model and current situation. When looking at the research design and questions a flattening of the work pressure is anticipated. In this section several simulation experiments will be conducted in which the control variable will be changed.
The first objective is to find the number of resources for the redesign with which the system has the same average queue length as the base model. Since the number of resources is an integer, the average queue length will probably not get exactly the same. Therefore the number of resources with a corresponding queue length which is closest to average queue length of the base model. Next to finding the optimal value for the redesign, more extreme values for the workforce will be simulated and the effects discussed.
Subsequently the performance of the simulated experiments is discussed.

7.3.1 Queue length

The average queue length is the system performance indicator with which the base model and the redesign can be compared with each other. The objective is to find out the number of resources which are required for the redesign process to perform the same in practice as the current situation. This means no overly full buffer and no trolleys and purchases with extreme tardiness.
According to the scheme showed in Appendix N Figure 38 (74) several experiments are run, by changing the number of resources available for the process. The result of this simulation study is shown in Figure 28 (44). The figure shows the difference in queue length with the base model, in percentage. Table 24 (79) in Appendix R shows the experiments with input parameters and the results as numerical output. The results of the simulation study indicate that the redesign performs almost the same as the base model in both the situation of [redacted] resources. The most optimal situation is [redacted] resources in which the number of resources is reduced to the maximum and the systems still performs practically the same as the base model.

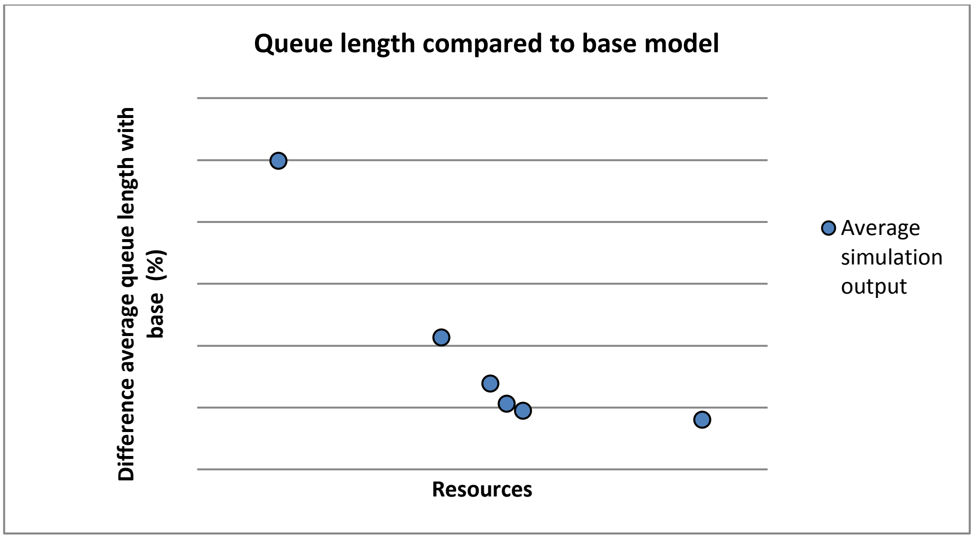

Figure 28: Queue length per workforce

7.3.2 Process time

Each experiment in the simulation study has an average queue length as described above. Another performance indicator is the total process time. This is the time needed to process both the internal auctioned trolleys and the incoming IAT 4 trolleys. Total process time for each experiment is shown in Figure 29. The total process time consists of the time needed to distribute all local auctioned trolleys plus the extra time needed to distribute the incoming IAT 4 trolleys. These specific times are shown in Appendix R; Table 26 (79) shows the numerical output and Figure 41 (79) and Figure 42 (80) show the graphical output of these times.

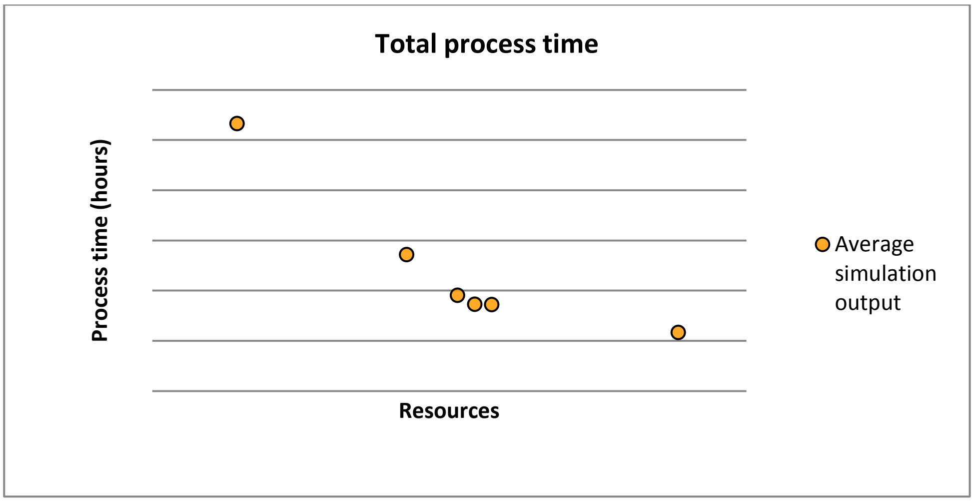

Figure 29: Total process time per workforce

7.4 Conclusions simulation

An important conclusion which can be drawn about the redesign that is gives the same performance compared to the base model with the use of less distribution workers. The average workforce can be reduced with [redacted] effective workers, from [redacted] workers in the current situation to [redacted] in the new situation. This is a reduction of [redacted] % of the total average number of effective distribution workers. Table 17 (45) and Table 18 (45) show the performance of both systems and the average process time to distribute the internal auctioned trolleys is the same.

Table 17: Performance summary base model

Base model	
Workforce	[redacted]
Average process time internal trolleys (trolleys)	[redacted]
Worked minutes	[redacted]

Table 18: Performance summery optimal redesign model

Redesign	
Workforce	[redacted]
Average process time internal trolleys (trolleys)	[redacted]
Worked minutes	[redacted]
Average process time incoming IAT 4 (trolleys)	[redacted]
Worked minutes	[redacted]
Average process time (trolleys)	[redacted]
Worked minutes	[redacted]

A smaller workforce is needed in the redesign model to process the same amount of trolleys compared to the base model. The base model is used in this context as reference point for the redesign. However the base model can also be used to assess the second redesign described in section 5.2. Table 17 and Table 18 also show the total amount of minutes worked by the workforce. When comparing these values it can be concluded that the workforce has 74 minutes on average to process the incoming IAT 2. This holds for the second redesign model, release of IAT 4 after distribution. The workers have to take the trolley from the buffer and drive it to the right aisle.

There are however some serious drawbacks to the redesign 2 model. Trolleys coming from the distribution process are customer related. This means the outgoing IAT 4 transactions have a much longer wait time in the distribution area.

Another result from sorting the transactions by customer is a significant smaller load factor compared to redesign 1. Trolleys are loaded with different types of casks and boxes, which results in unused space on the trolley. When transporting these trolleys inside the company building this is not a big deal. However for road transport this is not the case. More trolleys have to transported, resulting in more handlings and more truck movements.

The third effect of sorting the IAT 4 transactions on customer trolleys is that the outflow and consequently the inflow at another location are not smooth. Due to the large average waiting time, a lot of trolleys arrive late at the location they have to be. The workforce has to wait and the most work has to be done at the end of the process.

The last drawback of redesign 2 is that there is no possibility to reduce the workforce. By reducing the workforce less people are kept longer occupied. In contrast to this conclusion redesign 1 does provide this possibility.

8 Conclusions and recommendations

In this section the research question and its sub questions will be answered. Furthermore, recommendations and directions for further research are discussed in the final paragraph.

8.1 Conclusions and answers to research questions

In the previous chapters insight is given in the distribution process of flowers inside the company. The current arrangement of the distribution process has evolved over the years from highly manual to more automated nowadays. Just a few decades ago trolleys were distributed totally by hand. A distribution worker would take a trolley and walk in and out the lanes. This is replaced by motorized movement and distribution. However the distribution process is optimized over the years, it still has a strong local focus. However, mergers and acquisitions from the past years demand a focus which is more aimed to the network as whole.
In this conclusion the network focus will be discussed by first answering the sub questions and finally the main research question.

> *Which possibilities for network distribution can be setup?*

In chapter 5 the possibilities for network distribution are discussed. When looking at the different possibilities two types of possibilities can be observed. The first type is developed with the current situation in mind. These designs take into account that large amounts of capital are invested in the current infrastructure. The second type of network distribution designs takes a blank sheet of paper as starting point. In other words how can the process be set up if there was nothing operational at this moment. The design will have to be built up from scratch. Chapter 5 gives just gives a small first step in this direction, but this would be an interesting direction of investigation.

> *In which way do the processes have to be adjusted to achieve a logistic system which is able to perform network distribution?*

In line with the previous research question the different designs for network distribution require different adjustments of the processes. When looking at the leading redesign, release of IAT 4 before distribution, the adjustments to the distribution process are not very radical. A certain part of the distribution area will be reserved to transfer IAT 4 purchases. The connection from distribution area to

> *What are the advantages and disadvantages resulting from this adjustment and which one outweighs the other?*

In section 7.4 redesign release of IAT 4 before distribution is compared to the redesign 2. Redesign 2 is in itself not an actual redesign. In this scenario the distribution process is kept the way as it is right now. It is supplemented with transporting the customer trolleys between auction locations by taking them from the delivery gutters and putting them in trucks. The disadvantages outlined will cause unwanted delays and disruptions, which are not present in the release of IAT 4 before distribution redesign.

> *What are the effects of changing to network distribution on costs and operations?*

The performance of the systems, both the base model and the redesign, is outlined in chapter 7. The distribution workers have to work longer to fulfill all tasks. However, these operations are currently done somewhere else in the supply chain. The desired effect of keeping fewer workers occupied for a longer period of time works both ways. Les workers are needed to perform the handlings in the distribution process. In addition, these workers are provided with more work which keeps them occupied longer. Since extra services are provided for the buyers, the cost made for this service can be passed to the buyers using this service.

Since the flows between are grouped and consolidated, benefits resulting from economy of scale can be realized. This results in lower total cost and a higher profit margin on the IAT 4 service.

Does the change to network distribution result in a flattening of the work pressure for the different departments?

This sub question is already slightly addressed in the sub questions above. Chapter 7provides an extensive analysis of the impact on work pressure and workforce. The simulation study provides a possible lowering the workforce with an average of 7.2 % as result. This number can be different at other auction locations, because it highly depends on how large the fraction of IAT 4 transactions is in the total auctioned volume.

*Explore the impact on workload in the distribution process by introducing **network distribution***

The concept of network distribution is a progressive way of thinking for the company network. This report aimed to find the impact of implementing this type of distribution in the network. Currently the distribution is of a local nature which is not in line with the current size and position of the company.
Shifting to network distribution provides a much better service to the buyers using the platform provided by the company. In addition to this the implementation of network distribution results in a reduction of the workers needed for the distribution process. It is up to the responsible people inside the company if this reduction is large enough to be of benefit.

8.2 Directions for further research and recommendations

The research about the implications of shifting from local distribution to network distribution has given a good insight in a part of the processes going on inside the company. These insights have led to the following recommendations and directions for further research.

8.2.1 Recommendations

The following recommendations are made to the company.

1. Tracking system IAT 4 purchases after release

The IAT 4 purchases are transferred from the trolleys before entering distribution. Since the IAT 4 purchases are sorted by cask size (fustcode) transactions for different buyers are on the trolleys. The worker has to scan the trolley on which he puts the IAT 4 purchase. When the trolley arrives at the other locations and gets distributed the distribution worker knows for which buyers the products on the trolley are. The Voice system can tell how much casks the distribution worker has to transfer on location in a specific aisle.

2. Handling of inter auction transport

The loading, unloading and transportation of IAT 4 trolleys has to be a smooth and uniform process. This ensures a maximum utilization of the benefits of the proposed redesign. The Hubways concept seems to be an ideal solution for this question which ensures the control of the system staying with the company.

8.2.2 Directions for further research

Several directions for further research will be outlined in this section.

1. Analysis of other company locations

In this research an extensive analysis of the distribution process at [redacted] is made. Characteristics of the distribution process as well as the features of the purchases made by the byers are analyzed. This analysis served as input for the analysis of the research question. However, in a more ideal situation more input is desired for this research. Especially the inflow of IAT 4 purchases is a parameter which is valuable to know. In this project the inflow of IAT 4 is based on the outflow generated by the simulation. However when the outflow of IAT 4 with its directions is known for all locations the total inflow of IAT 4 is also known for every location.

In line with the flows of IAT 4 the characteristics of the distribution process of every location have to be analyzed. As long as all distribution processes are not exactly the same, every location needs a customized approach to determine the handling of IAT 4. Things like workforce, arrival rate and total auctioned volume are unique for every location. The expectation is that in the future the distribution process will get more and more the same one the different auction locations. Until this time customized analyses and processes are required.

2. Extension of analysis

Some parts of the analysis can use some extra attention. Especially the handling time of the trolleys in the distribution process is subject for this extra analysis. The current handling model is constructed using a low number of empirical measurements. This resulted in a linear distribution time graph. By recording the data of this process a solid analysis of this process can be made.

The voice system can be a good option to retrieve the data from, since this system relies on a database with which information for the process is exchanges. At time of this research the system was in a very early state of use which made this information unavailable.

3. Landscape shifting redesigns

Section 5.3 provides a set of possible ground shaking redesigns. These redesigns might not be feasible or desirable. It is important to keep these possibilities in mind for the long term. A remark which has to be made with this direction for further research is that the floriculture is very rigid and hangs together of assumptions. However these kind researches can be of great benefit for the organization.

8.2.3 Limitations

In this section some of the limitations of the research project are outlined. This is in line with the directions for further research which already cover part of the limitations of the analysis section.

1. Goodness of fit

In this thesis several statistical distributions are fitted on the data coming from the processes. In a lot of cases the large amount of observations made the use of common goodness of fit tests impossible. In this case the square error is used to assess goodness of fit.

2. Model validation

For the distribution process, modeled in the simulation experiments, no data is available about individual actions is available. This makes the validation of the models difficult, because other process data has to be used which might not be as usable as information about actions in the distribution process.

Overview of abbreviations

IAT	Inter Auction Transport
KOA	Koop Op Afstand
LDA	Logistieke Dienstverlening Aanvoer (Logistical Service Supply)
LDK	Logistieke Dienstverlening Kopers (Logistical Service Buyers)
TLN	Transport en Logistiek Nederland (Transport and Logistics Netherlands)
VGB	Vereniging van Groothandelaren in Bloemkwekerijprodukten (Association of Wholesalers in Floricultural Products)

Buyer trolleys/Customer trolleys: Trolleys can be divided into two groups; trolleys coming from growers getting distributed after auction, trolleys in the distribution area linked to a buyer by a number in the floor in front of this trolley.

Transactions/Purchases/Buys: Buyers purchase a part of the content of a trolley in the auction process

IAT 4: Inter Auction Transport type 4; the kind of transactions which has to be repositioned after auctioning.

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List of figures

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Appendix A

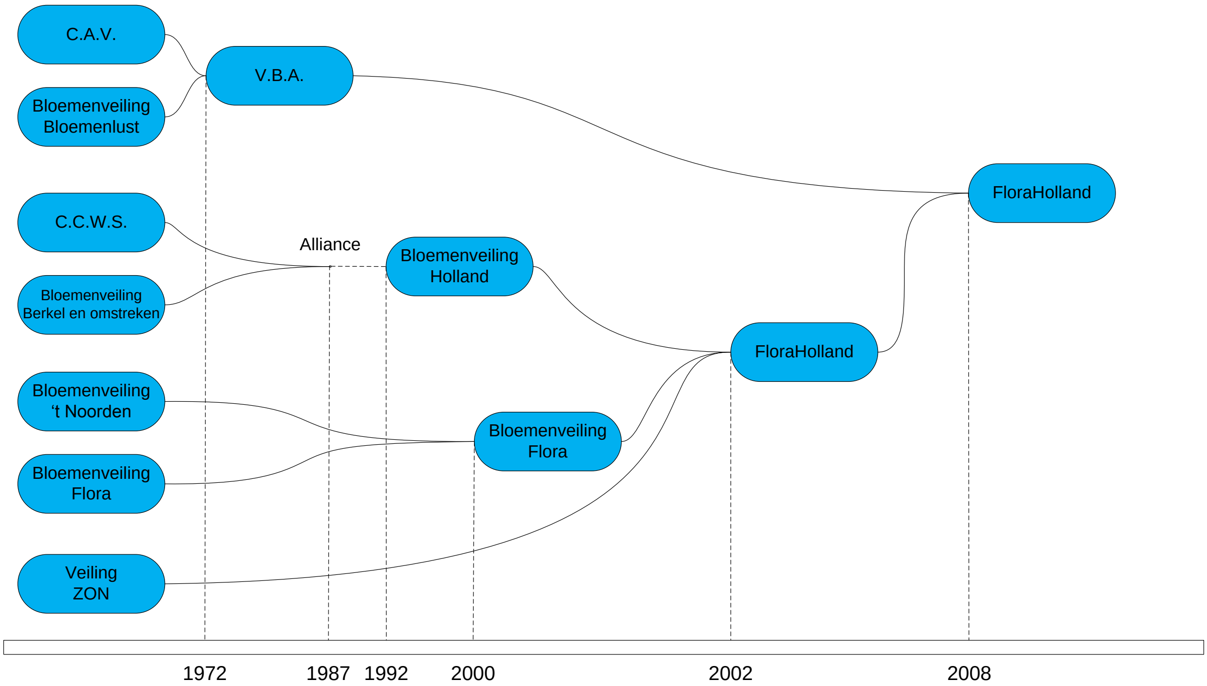

Figure 30: History of the company

Appendix B

Four different types of IAT defined by Jonkman (2010). They are caused, ordered and paid for by different parties, internal and external to *the company*.

1. Growers supplying to different auction locations deliver their products at the nearest locations and subsequently the products are transported by a collective floriculture transporter to the other locations.
2. The Import Handling departments receive products destined for another auction location and have these transported to that location.
3. Products sold through *Connect*, supplied to one auction, sold to a buyer at another auction, have to be transported there.
4. Buyers using remote buying services (KOA or KOA+) buy products at several auction locations and have these transported to the auction location their box is situated. For example, buyers or collective floriculture transporters consolidate products bought at different auction locations before distributing them to their final customers.

Appendix C

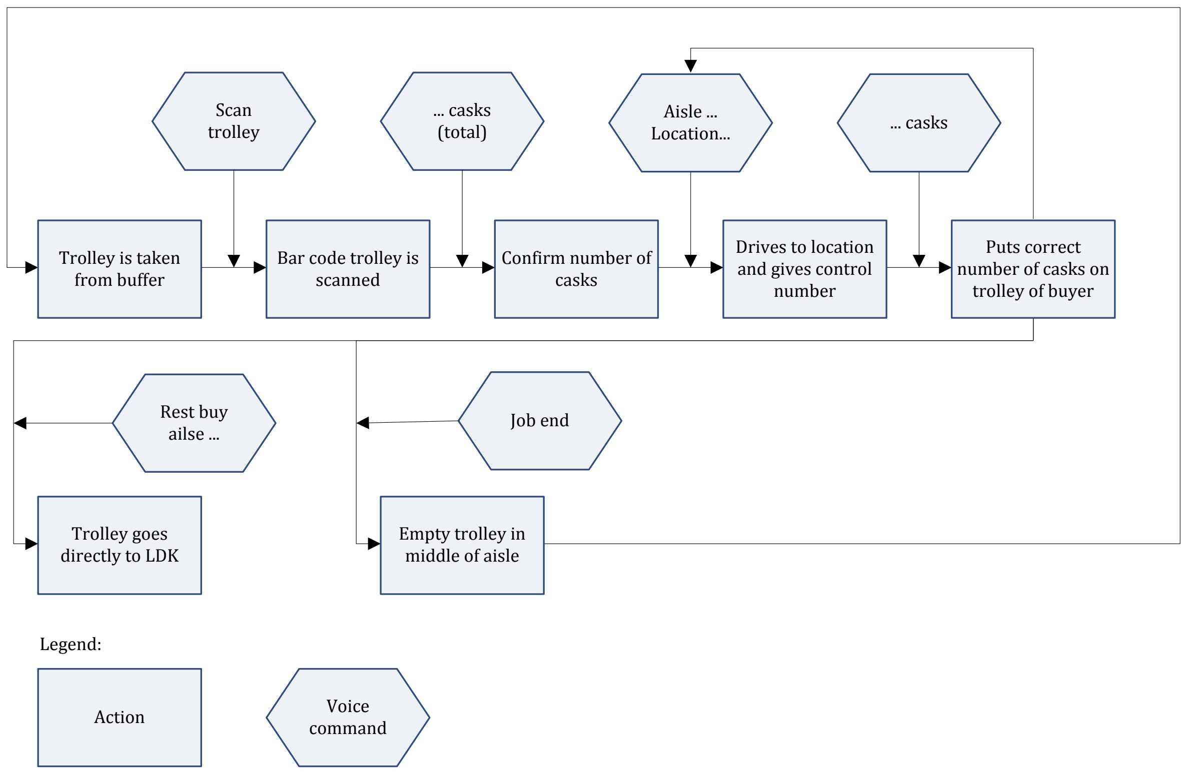

Figure 31: Distribution process using Voice ([redacted])

Appendix D

Table 19: Auction data sample

Datum	PP/SB	UAB	Volgletter partij	Stw.nr. bij veilen	STW nr. einde distributie	transactie nr.	Kooptype	# Fusten	Klok-nummer	Veiltijd	EKB tijd	Kowadi tijd	Aflever locatie	Administratie nummer	Volledige naam	Produkt naam
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Appendix E

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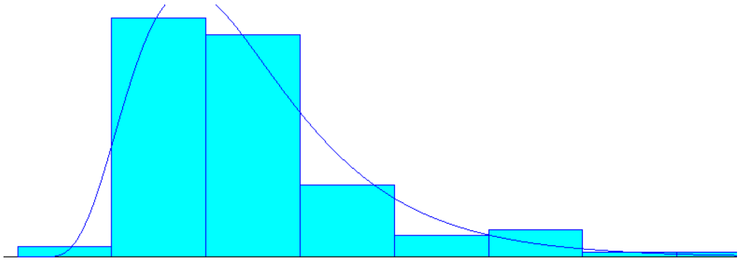

Figure 32: Data fit arrival 27-09-2011

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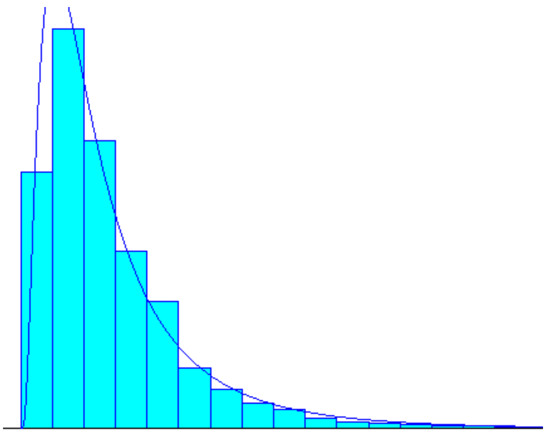

Figure 33: Processing distribution fit 27-9-2011

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Appendix F

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Appendix G

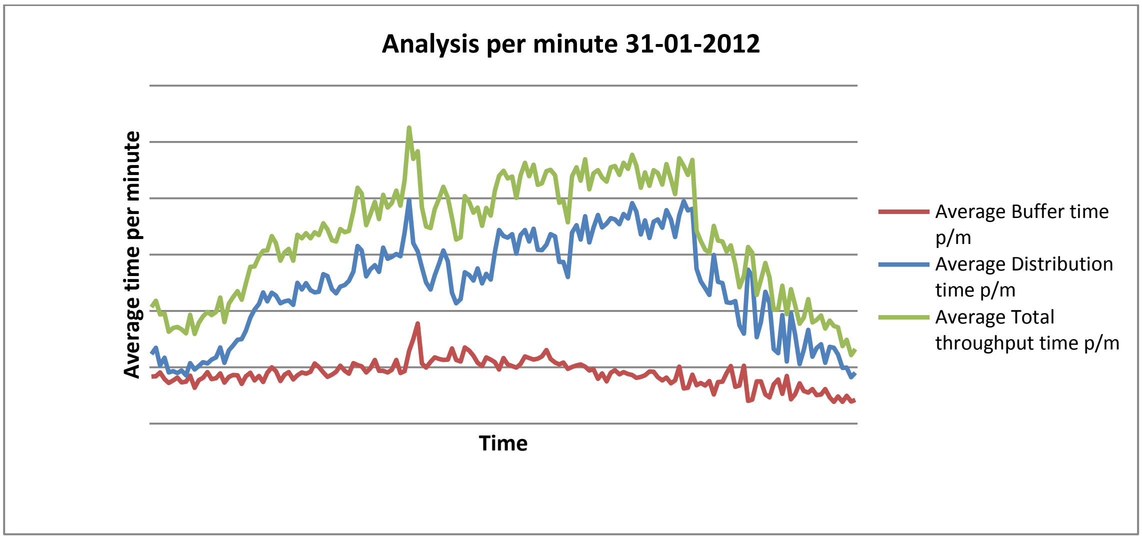
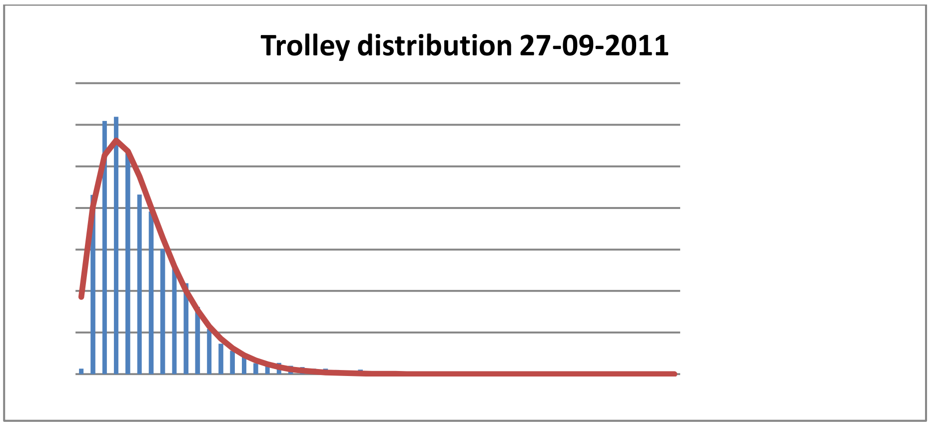


Figure 34: Average parameters per minute

Appendix H

Figure 35: the company auction trolley



Distribution Summary 27-09-2011

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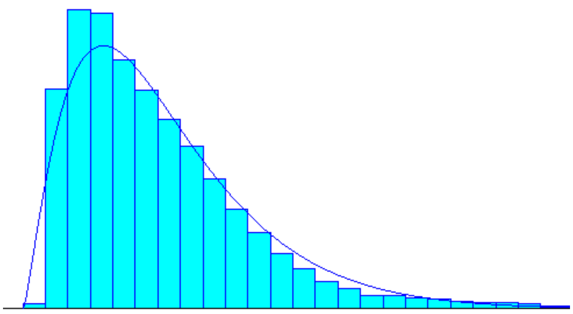
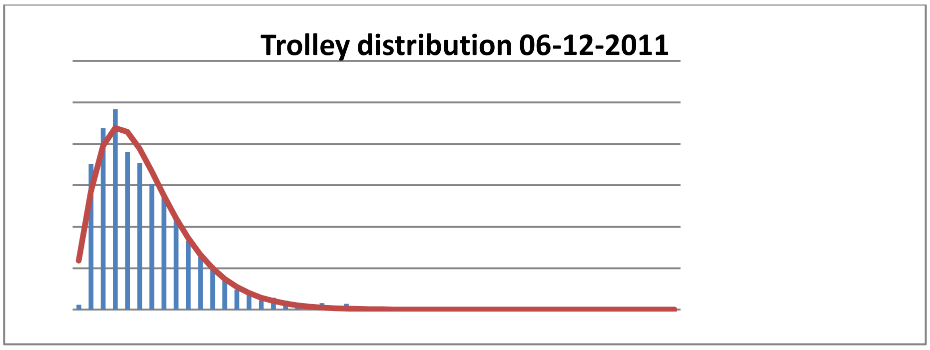
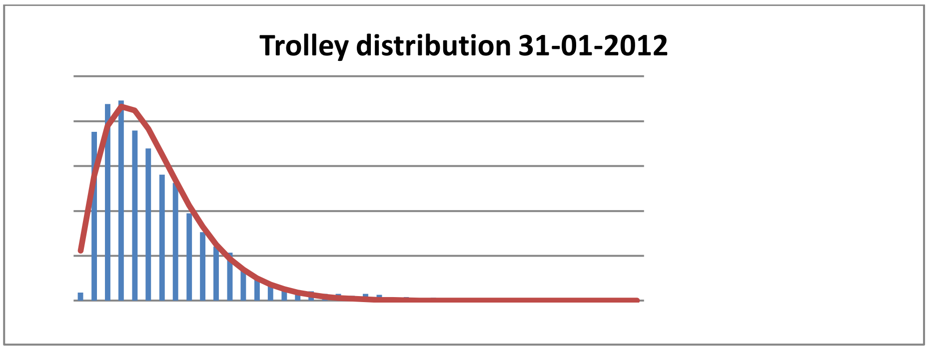
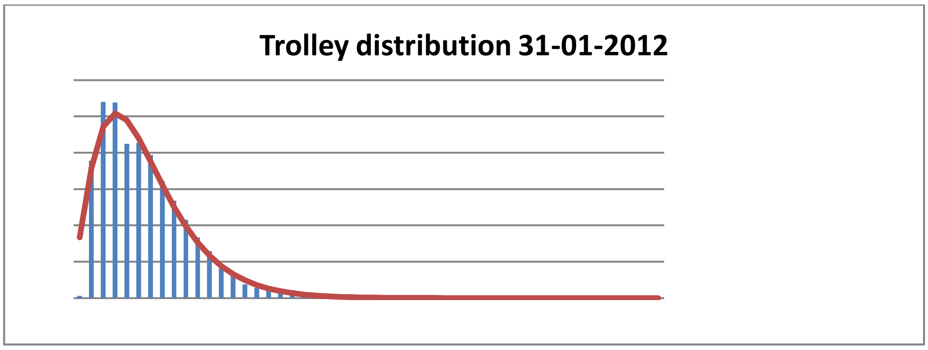
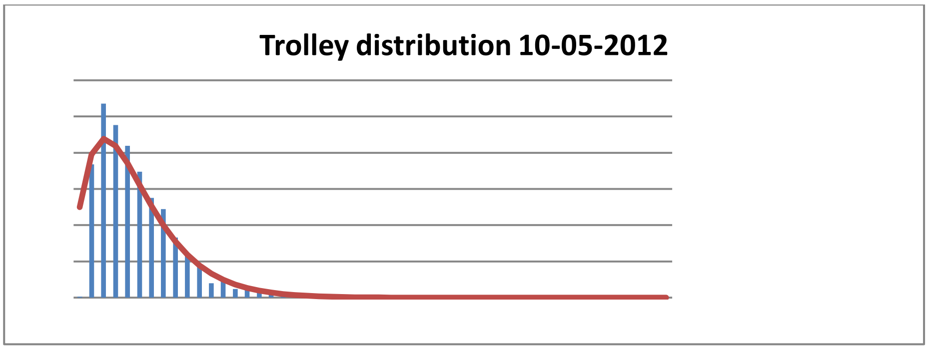


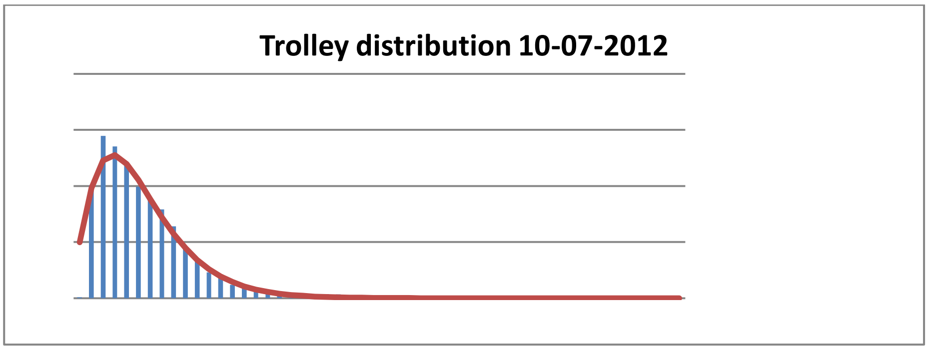
Figure 36: Trolley distribution fit 27-09-2011


Trolley distribution 06-12-2011


Trolley distribution 31-01-2012


Trolley distribution 31-01-2012


Trolley distribution 10-05-2012


Trolley distribution 10-07-2012

Appendix I

[redacted]

[redacted]

Appendix J

Table 21: base time

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Table 22: Transfer time

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Table 23: From buffer to first aisle

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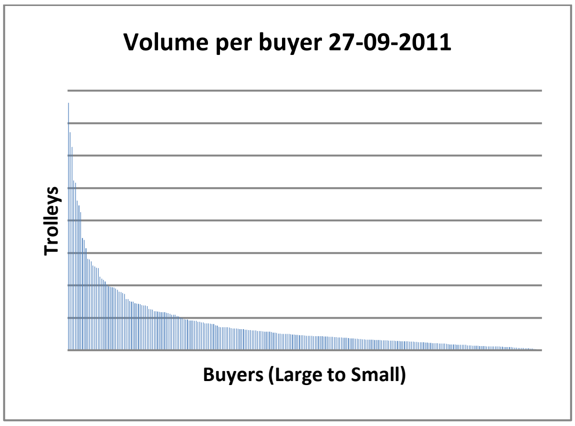
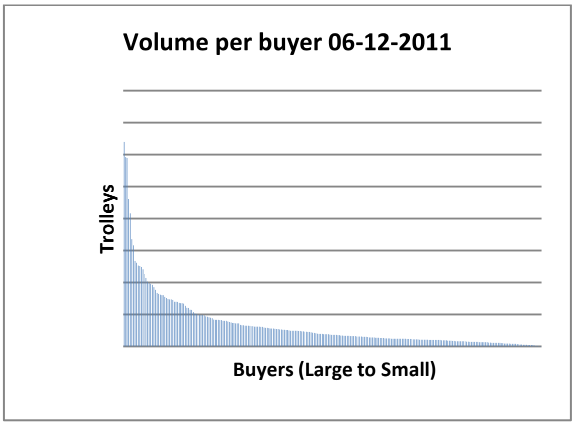
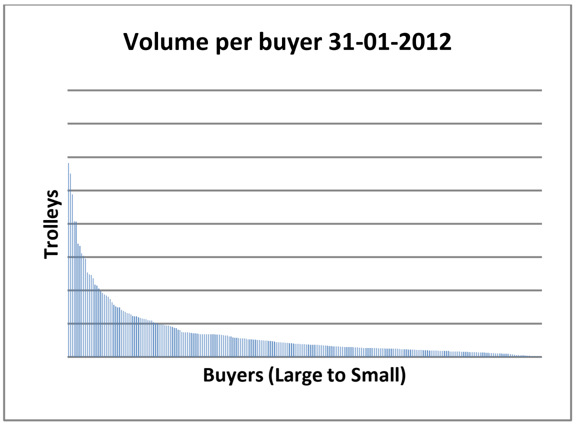
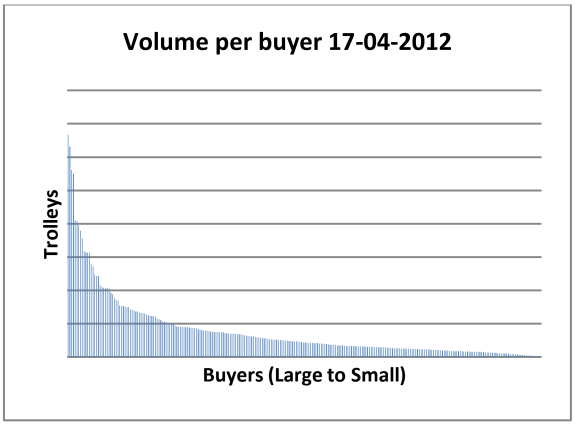
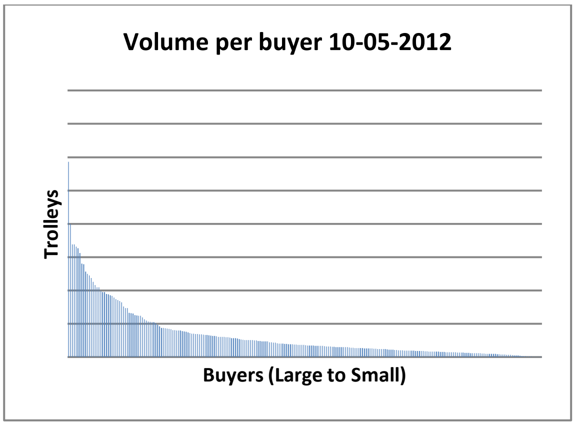
Appendix K

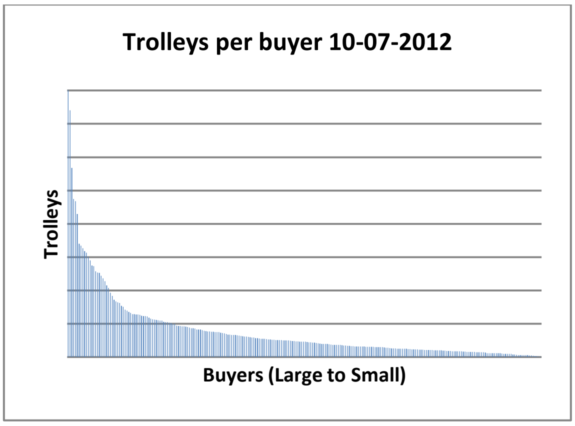












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Appendix L

Fraction trolleys with IAT 4

27-9-2011		
Total number of trolleys	Only for NW	With ext.
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

6-12-2011		
Total number of trolleys	Only for NW	With ext.
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

31-1-2012		
Total number of trolleys	Only for NW	with ext.
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

17-4-2012		
Total number of trolleys	Only for NW	with ext.
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

10-5-2012		
Total number of trolleys	Only for NW	with ext.
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

10-7-2012		
Total number of trolleys	Only for NW	with ext.
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

'n-1' method

$$\sqrt{\frac{\sum(x-\overline{x})^2}{n-1}} \qquad (13)$$

Volume of IAT 4 per trolley

27-9-2011			
Average extern	All trolleys	Trolleys with NW	Mk only ext.
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6-12-2011			
Average extern	All trolleys	Trolleys with NW	Mk only ext.
[redacted]	[redacted]	[redacted]	[redacted]

31-1-2012			
Average extern	All trolleys	Trolleys with NW	Mk only ext.
[redacted]	[redacted]	[redacted]	[redacted]

17-4-2012			
Average extern	All trolleys	Trolleys with NW	Mk only ext.
[redacted]	[redacted]	[redacted]	[redacted]

10-5-2012			
Average extern	All trolleys	Trolleys with NW	Mk only ext.
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10-7-2012			
Average extern	All trolleys	Trolleys with NW	Mk only ext.
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Appendix M

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Appendix N

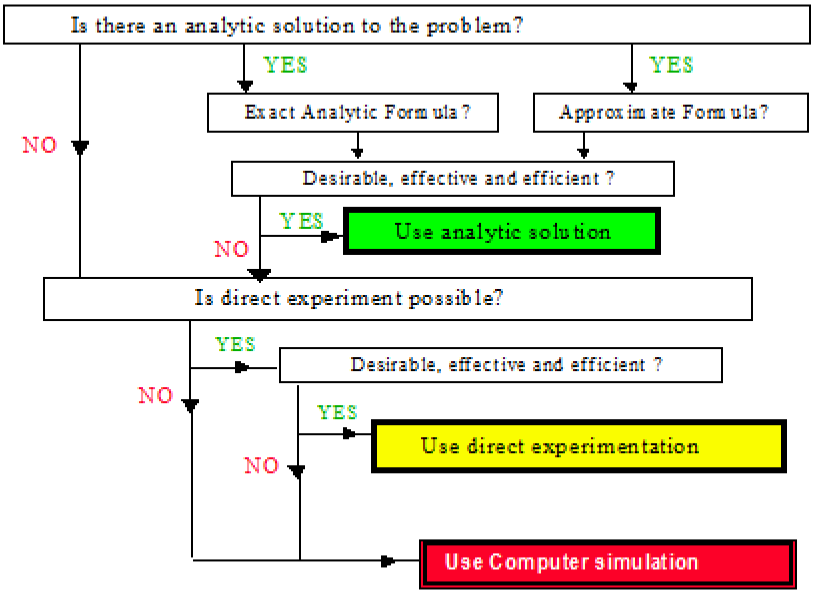

Figure 37: The simulation decision tree (Goossenaerts & Pels, 2010)

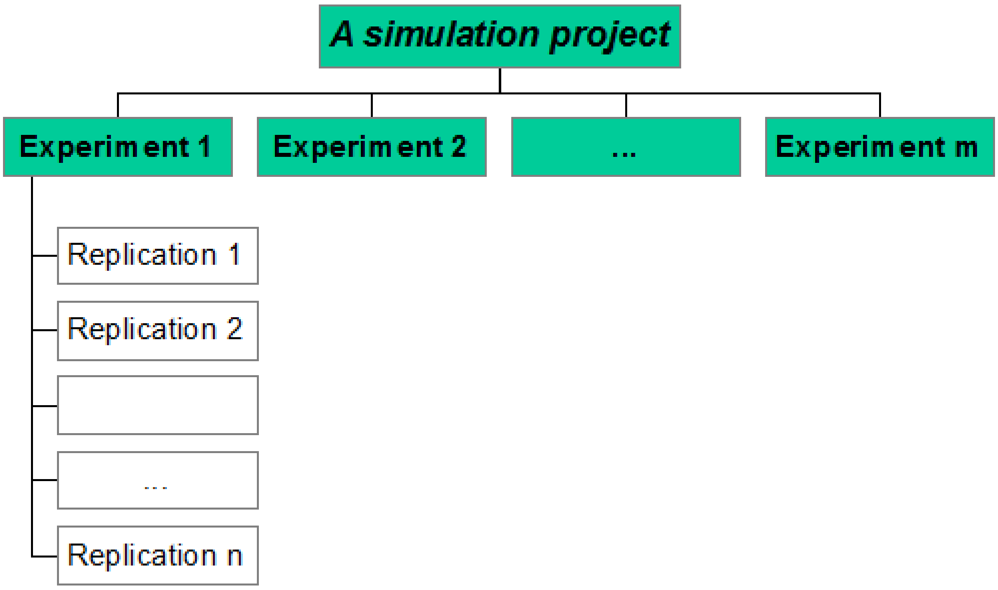

Figure 38: Experiments and replications (Goossenaerts & Pels, 2010)

Appendix O [redacted]

Appendix P

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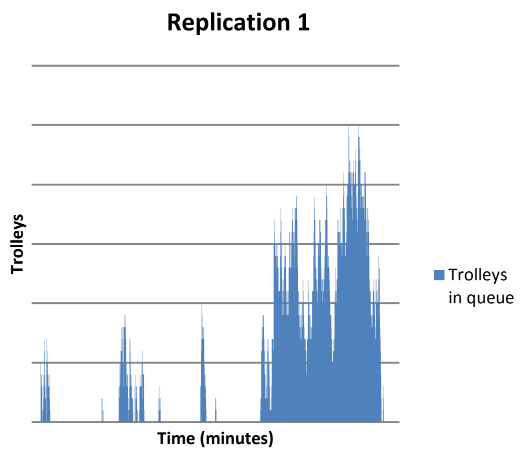
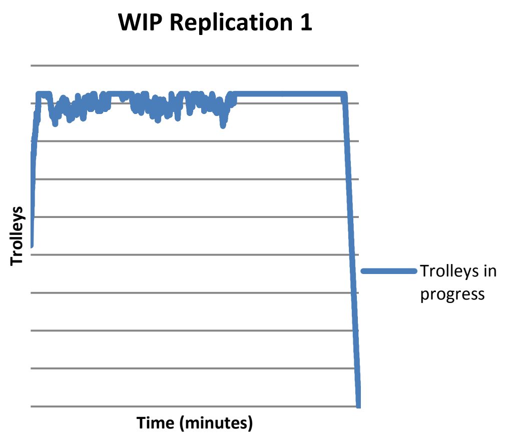
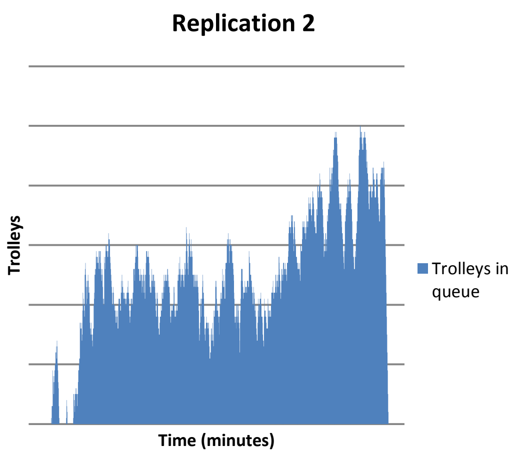
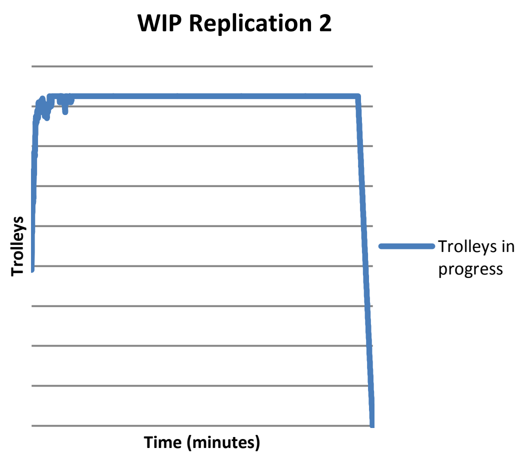
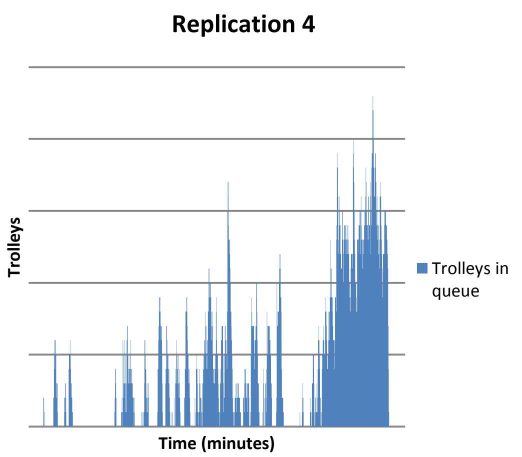
Appendix Q

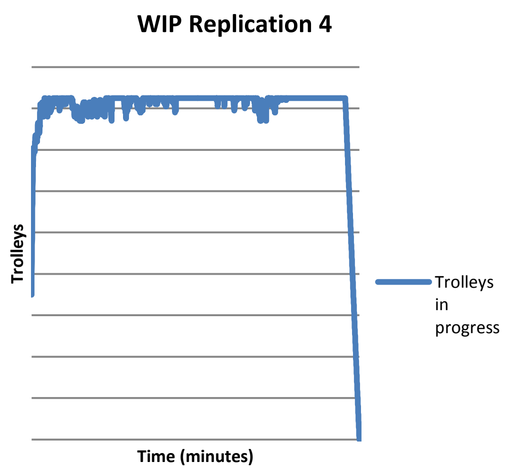

Replication 1
Trolleys
Time (minutes)
Trolleys in queue

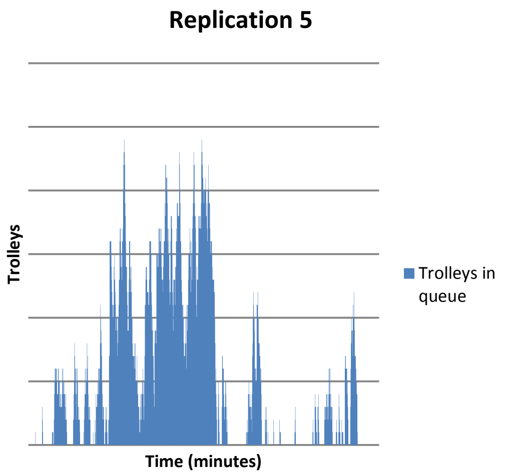

WIP Replication 1
Trolleys
Time (minutes)
Trolleys in progress

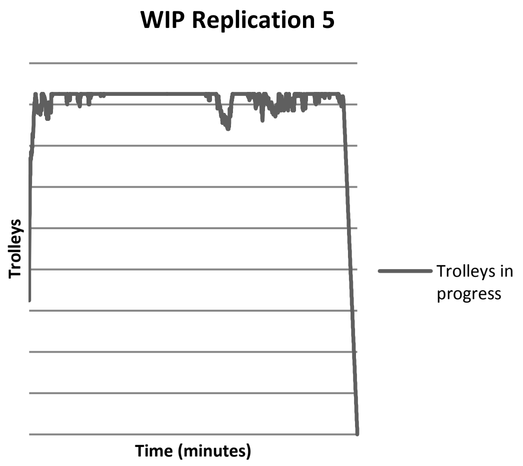

Replication 2
Trolleys
Time (minutes)
Trolleys in queue


WIP Replication 2
Trolleys
Time (minutes)
Trolleys in progress


Replication 4
Trolleys
Time (minutes)
Trolleys in queue


WIP Replication 4
Trolleys
Time (minutes)
Trolleys in progress


Replication 5
Trolleys
Trolleys in queue
Time (minutes)


WIP Replication 5
Trolleys
Trolleys in progress
Time (minutes)

Appendix R

Table 24: Simulation study redesign

Simulation study redesign					
Number of resources	Average queue length	Confidence Interval		Difference with base model	Difference with base model (%)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

Table 25: Average queue length base model

$\bar{X}_i$	[redacted]	
s	[redacted]	
Confidence Interval (α=0.05)	[redacted]	[redacted]

Table 26: Performance per experiment

Number of resources	Total time	Internal dist time	Extra Dist. time for IAT 4	Extra Dist. time for IAT 4 (%)
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

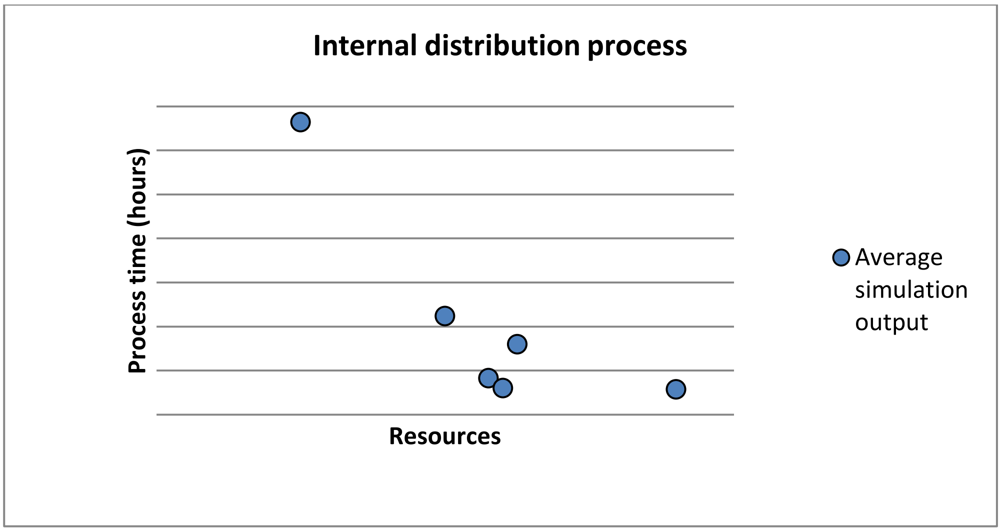


Figure 41: Distribution time internal auctioned trolleys

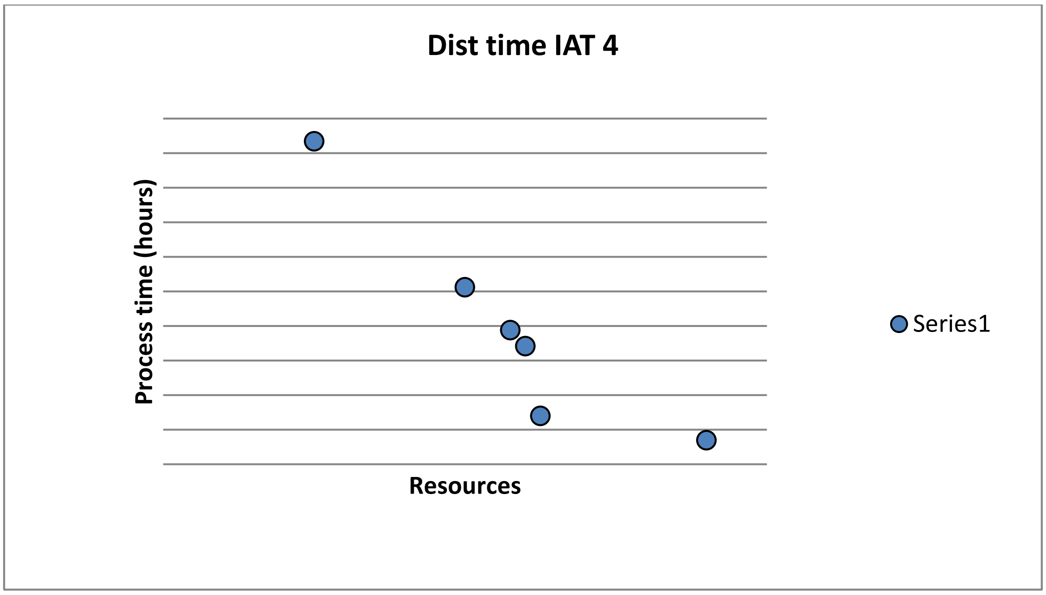


Figure 42: Extra time needed for distributing IAT 4