UNIVERSITY OF TWENTE.

Faculty of Industrial Engineering & Management

Bachelor Thesis

Improving the lead time of consumable deliveries at Company X

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Management summary

Company X produces metal working production machines that can perform several different adaptions to metal beams and sheets including sawing, laser cutting, plasma cutting, autogenous cutting, milling, and bending. The machines consist of two types of components: consumables and parts. Parts are used to build the machine. Examples are metal sheets, bolts, nuts and saw tables. Consumables are used to make adaptions to the metal, which wear out over time and therefore must be replaced repeatedly. Examples are drills and saws. Next to selling the machines to customers, Company X also supplies the consumables. Currently, the lead time of consumables to customers in the Middle east, Great Britain and North Africa is considerably high. High lead times are unwanted as customers become dissatisfied and leave to competitive companies. The research question therefore is; *How can the lead time of consumable deliveries to global customers be improved, balancing costs and lead time performance?*

Four main causes for the high lead time can be identified: consumables can be out of stock and therefore have to be reordered from the suppliers, the time a shipment spends at the border patrol is considerably high in some countries, the time it takes to finish the paperwork that is necessary to send orders to some countries and the distance shipments travel from the warehouse at destination X (Netherlands) to the customer's destination. In this research, the distance between the warehouse and the customers is aimed to be decreased. The other three causes are either external factors and are not possible to solve or are not an Industrial Engineering and Management related problems. The part of the lead time that is caused by the distance is called delivery time. This research thus aims to decrease the delivery time that is part of the lead time and only includes the time between the departure of the shipment from the warehouse to the delivery of the shipment to the customer.

To assess improvements after theoretically implementing the solution, a set of key performance indicators is constructed. The average distance, weighted average distance, maximum distance, transportation costs and renting costs are indicators on which the performance of the solution is determined. Currently, the average delivery time for all countries is 7 to 8 days. The transportation costs are €327,249 per year. The average distance from the warehouse at destination X to the customers in The Middle East, Great Britain and North Africa is 1,523 kilometres. The maximum distance is 5,108 kilometres. The average weighted distance is 14,750.

To decrease the large distance from the warehouse to the customers, warehouses can be utilized from which the orders can be shipped to the customers. These warehouses should perform activities such as order picking, inventory management, customer service and retour management. These activities can be performed by a product fulfilment centre. Therefore, this type of warehouse is chosen to be utilized in the discussed regions.

The optimal number of and the location of the warehouses are calculated with the use of a P-median model. Several other models have been evaluated. The main reasons for using the P-median model is that the model is fairly simple to solve with a small amount of data and the objective function is minimizing the weighted distance, which is the end goal of this research.

The P-median model uses a finite set of possible warehouse locations and a finite set of demand points which are the customers of Company X. For the set of warehouse locations, a grid with evenly spaced points is used. This grid spans the map and is placed such that all customers are included. To find the optimal warehouse location, the process is split up into two phases. The first phase uses a coarse grid to keep the run time of the model low. From this phase, it became clear that two is the optimal number of warehouses. Building two warehouses entails the smallest total costs because the transportation costs decrease more than the increase in renting costs. Furthermore, building more than two warehouses does not give the same improvements in key performance indicator values as building one or two warehouses. The extra investment in renting costs is thus not worth the additional small improvements. It became also clear to which warehouse customers are assigned to. The second phase

uses a P-value of 2 and creates two smaller grids with a distance of 50 kilometres between the points. One grid for the cluster in the Middle east and one for the cluster in Great Britain. The smaller grid provides more accurate warehouse locations. The final warehouse location is located at coordinates (53.84, 2.65) for Great Britain. The warehouse in The Middle East is located at coordinates (29.26, 48.15).

The improvements after theoretically implementing the solution are promising. The average distance from the warehouses to the customers decreased from 1,523 to 798 kilometres. The average weighted distance decreased from 14,750 to 3,976. The maximum distance decreased from 5,108 to 2,309 kilometres. The average delivery time decreased from 4 days and 12 hours to 1 day and 22 hours. The outbound transportation costs decreased from €327,249 per year to €103,171 per year.

The main research question that is stated in the beginning can be answered. Building two warehouses at the coordinates mentioned before will decrease total costs by €84,078 per year and decrease the delivery time from 4 days and 12 hours to 1 day and 22 hours.

Future research is needed to verify that these coordinates are indeed the optimal locations. The optimal location does not only depend on the weighted distances but also on the political situation in a country and the presence of proper infrastructure such as roads, sea and air ports. The locations solutions found by the model should therefore be assessed on these factors before the solution is implemented. Furthermore, it is highly likely that no public warehouse is available at the exact location. Therefore, a public warehouse has to be found close to the coordinate point

Preface

In front of you lies my Industrial Engineering & Management bachelor thesis: “Improving the lead time of consumable deliveries at Company X”. Company X provided me the opportunity to utilize my skills logistics management, specifically facility location management, and programming skills to help find a solution to lengthy delivery times of consumables to three global regions.

I want to thank Company X for the opportunity of executing this research at their fascinating company. Furthermore, I want to thank T. ter Hedde for the support and effort he put in his guidance. I highly appreciate the trust he had in my process, which motivated me to use critical thinking skills and become an independent thinker and achieve the result I intended. I also want to thank the Parts and Consumables team for the pleasant working environment and open minded helping attitude. I hope to meet or work with both T. ter Hedde and the team in a later stage of my career.

Next, I want to thank D. Demirtas and D. Guericke for their excellent feedback and encouragement throughout the research and writing process. I appreciate the freedom both supervisors gave me in the whole process and would like to work with them in a future research or project.

I wish you a pleasant reading experience.

Gijs Renskers

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1. Introduction

In this chapter, an introduction to the research will be given. The first section gives an introduction to the company by explaining the work field and activities that are executed by Company X. The second section explains the encountered problem. The goal and a brief introduction to the current situation are given after which the core problem within the research is indicated. In the third section, the scope of the research is explained. In the fourth section, a description of the deliverables is given which is followed by a list of research questions that break down the main question into manageable tasks.

1.1 Company X B.V.

Company X BV is a family business that was established in 1970. Since then the company has designed and produced metal-working machines and whole metal-working production lines. In 1976, the company started designing and producing steel constructions for a wide variety of applications. Therefore, in 1980, two different companies were established; Company X Steel Machinery BV, which is specialized in designing and producing metal working machines, and Company X Steel Construction, which is specialized in designing and producing steel constructions. Currently, Company X has a total of 4 branches with 500 employees from where machines and steel constructions are produced and then shipped to customers located in a wide variety of global countries.

To give a better understanding of the capabilities of the machines that are produced by Company X Machinery, a brief elaboration on the machines that Company X produces will be given.
The metal working machines that Company X produces can work hard and heavy metal sheets and beams autonomously. The machines can perform a variety of different operations on the metal, including drilling, sawing, laser cutting, plasma cutting, autogenous cutting, milling, and bending. Several machines can perform a combination of these operations. The cutting and drilling machines either make use of a flatbed cutter, where the tool moves along the metal sheet or beam or the machines use a transit system, where the metal sheet or beam moves through the machine and the tool stays in place. Figure 1 depicts a flatbed cutting machine where the tool moves across the material. A transit cutting, drilling and milling machine, where the tool stays in the same place and the material goes through the machine, is depicted in Figure 2.

Figure 1:Plasma and autogenous cutting machine(flatbed cutter)


Figure 2: Drilling, cutting and milling(transit system)

There are two distinct names for the parts that are used to build the machines and keep them operational: consumables and parts. Consumables are the components that are used to perform the operations on the material. Consumables wear out over time and thus have to be replaced repeatedly, such as drills and saws. Parts are used to build the machines. Examples are the engine, metal sheets, nuts and bolts and working tables. Parts usually do not wear out over time, although they can break.

Company X supplies both the metal working machines as well as the consumables and parts to their customers. As Company X wants to maintain current customers and acquire new customers in the regions of North Africa, The Middle East and The United Kingdom and consumables are an essential part of the machine to keep it operational, the focus of this research lies on the improvement of the consumable lead times to those regions. The lead time of consumables is the difference in time between the customer placing an order and the order being delivered to the customer. A more elaborate explanation of the motivation and the scope of the research will be given in a later part of the report.

1.2 Problem identification

1.2.1 Motivation

Currently, the consumables are shipped from the branch at destination X in The Netherlands to customers in the Middle East, North Africa, and Great Britain. The lead time of consumables to these customers is considerably high. Four main causes can be identified after interviewing several employees at Company X. It can occur that consumables are out of stock and have to be ordered from the suppliers. The second cause is the amount of paperwork that is needed to send consumables to customers located outside of Europe. The long distances between customers in the concerned regions and the warehouse at destination X make it very hard for Company X to react adequately to the demand from customers. Lastly, the border patrol in countries outside of Europe delays the shipments and increases the lead time.

The lead time can be split up into two time periods. The first period is between the placement of an order and the pickup by the delivery company. The second period is between the pickup by the delivery company and the delivery of the consumables to the customers and is called delivery time. The consumable stockouts and paper work delays occur in the first period whereas the long distance and border patrol are causes taking place in the second period. The long border patrol time and consumables being out of stock are external causes, and the paper work problem is not an Industrial

Engineering and Management related problem thus these problems will not be included in this research. Therefore the focus of this research is on decreasing the delivery time which is part of the total lead time, by decreasing the distance between customers and the warehouse. The delivery time of consumables to customers in Great Britain, The Middle East and North Africa varies from 3 days to 15 days. The delivery time in days per country is depicted in Table 1 below.

Country	Average delivery time(days)
Great Britain	2.9
Qatar	4.2
United Arab Emirates	4.4
Israel	5.3
Saudi Arabia	5.6
Morocco	7.8
Uzbekistan	8.3
Turkey	10.6
Kuweit	11.2
Tunisia	15.4
Algeria	NODATA
Egypt	NODATA
Azerbaijan	NODATA

Table 1: Average delivery time per country

To substantiate the relevance of decreasing the delivery time, an insight into the relation between delivery time and customer satisfaction is discussed. According to Dündar, & Öztürk,. (2020), there is a moderately positive significant relationship between a short delivery time and customer satisfaction. Furthermore, there is a highly positive and significant relationship between customer satisfaction and customer loyalty. Therefore current customers will theoretically be more satisfied and therefore less tempted to go to the competition when delivery times are short.

After interviewing employees of Company X, it became clear that the revenue stream of Company X mainly arises from machinery sales. A graphical representation of revenues is not given in this report as this can be identified as sensitive information. It can be stated that currently, 10 per cent of Company X's revenue comes from consumables sales, while 90 per cent of the revenue comes from machinery and maintenance sales. When insecure periods arise, a decrease in machinery sales is a consequence of companies postponing their investments. Within Company X a large decrease in machinery sales was felt during the Corona pandemic. The sales of consumables are a stable revenue stream, especially if the largest proportion of the consumable sales originates from contract deals. Increasing consumable sales by lowering the delivery times can counteract decreased machinery sales in potentially insecure times. Therefore, in the long run, the goal of Company X is to increase their revenue from consumables sales to 20-25 per cent of its total revenue. Moreover, currently Company X gives a discount to customers that expect a low delivery time that can't be guaranteed. These discounts increase the total costs and thus decrease total revenue.

Decreasing the delivery time per region will thus retain current and attract new customers which leads to an increase in revenue from consumable sales, potentially counteracting periods of insecurity. Moreover, by increasing the number of customers that buy consumables, revenue will increase and a higher profit can be achieved, even outside insecure periods. Gaining insight into the delivery times per country after improving them, gives Company X the possibility to provide customers with attractive offers regarding the delivery time of consumables.

1.2.2 Goal

The goal of this research is to improve the delivery time of consumables to customers located in the countries depicted in Table 1 in Section 1.2.1. Currently, an average of 7 to 8 delivery days is standard to these countries. In terms of time, the objective of this research is to bring down the average delivery time of all countries to 2 days.

1.3 Scope

The focus of this research is to shorten the delivery time of consumables to customers in The Middle East, North Africa and Great Britain due to their considerably high delivery times in comparison to customers in other regions. Furthermore, the machinery sales market in these regions is increasing in the past few years and thus the demand for consumables with a fast delivery time is high. There are several causes for the long delivery time which are already mentioned in Section 1.2.1 from which the distance between customers and the warehouse lies inside the scope of this research. Different solutions for the large distance will be explored with the use of existing literature after which the best solution is chosen. This thesis also includes literature research on some aspects of the implementation of the future solution such as the warehouse type and the warehouse functions which are used as an advice in the solution design that is handed over to Company X. Furthermore, important aspects when locating a warehouse are discussed, however they are not applied to the practical solution design because of time constraints.

1.4 Research design

To report the chosen solution to the interested parties, including Company X, several deliverables are constructed

1.4.1 Deliverables

KPI’s

To generate a solution that fits the company's requirements, a list of key performance indicators, also known as KPIs, is made. The KPIs ensure that the benefits of the chosen solution are measurable. Therefore, the first deliverable is a list of KPIs to assess the success of the chosen solution.

Location model

A mathematical model including the data that is used to determine the optimal theoretical solution will be handed over to Company X as the second deliverable. Company X can use the model to examine the reasoning behind the solution choice, so a possible future implementation can be substantiated. The cause of the high delivery time is the large distance between the branch at destination X and the sales market in global countries. Therefore the deliverable is a mathematical model describing the optimal location(s) for (a) new warehouse(s) near those regions and advice on where to place the warehouse(s).

Experiments

Experiments with different model setups and model parameters are executed and the results are handed over to Company X so the reasoning behind the optimal solution is clear.

1.4.2 Research questions

To solve the stated problem, several research questions have been constructed to divide the problem into manageable tasks. The main research question is: *How can the lead time of consumable deliveries to global customers be improved, balancing costs lead and time performance?* The constructed research questions are:

What are the problems that are involved in the current order and delivery process?
To determine the current problems that are involved in the order and delivery process, interviews with employees within the parts and consumables department of Company X are conducted. The problems are described and the problems that will be solved are selected. This research question has already been answered in Section 1.2.1.

What does the current inbound and outbound delivery process of Company X look like?
To get a better understanding of the current distribution process of consumables, a flowchart is made to visualize the flow of products. Furthermore, the current locations of the customers and suppliers are mapped. This research question is answered in Section 2.1.

What KPIs should be used to measure the success of the solutions?
A list of KPIs is constructed to measure the performance of the current distribution network and any improvements on the distribution network after implementing the theoretical solution. This question is answered in Section 2.4.

What are the current values for the constructed KPIs?
KPIs will be used as a benchmark to compare the current situation and future situation in multiple aspects. The current values of the KPIs are established with the use of data retrieved from Transsmart. Transsmart is the system in which shipments with corresponding information are stored. This question is answered in Section 2.5.

What is the best type of storage facility that can serve as a solution for the proposed problem?
There are multiple facility types, each having different handling characteristics. To determine the facility that most fits the problem that is faced in this research, existing literature is used to investigate the different types of warehouses. This question is answered in Section 3.4.

What is/are the optimal location(s) for the warehouse(s)?
To determine the optimal location for the warehouses, several sub-questions have been constructed:

a. What factors are of importance when choosing a location for the storage facility?(Section 3.3)
b. What models can be used to optimize the location of the new storage facility? (Sections 3.5)
c. How many warehouses are optimal? (Section 6.3)
d. What is/are the optimal location(s) for a storage facility(ies) based on the model? (Section 6.4)

What improvements in KPI values are made as a result of the research?
To determine the effectiveness of the solution, the KPI values after implementing the solution are compared to the KPI values in the current situation. This question is answered in Sections 6 and 7.

1.5 Conclusion

Company X is a family business that produces metal working machines that can perform a variety of adaptions to steel in multiple shapes. Next to producing the machines, Company X also delivers the parts and consumables which are necessary to keep the machines operational. Currently, the delivery time of consumables from the warehouse at destination X to the customers in The Middle East, North Africa and The United Kingdom is too long with an average of 7 to 8 days. The main research question therefore states: *How can the lead time of consumable deliveries to global customers be improved, balancing costs and lead time performance?* It is aimed to decrease the average delivery time to 2 days. The delay is attributable to several reasons, namely; the extensive amount of paperwork, delays at the border patrol, consumable stock-outs and the large distance between the warehouse and the customers. The distance is chosen as the core problem to be solved because the other causes are either external causes or not related to Industrial Engineering and Management. Decreasing the delivery time increases customer satisfaction and loyalty. To divide the problem into manageable tasks, sub-questions are constructed.

2. Current situation

In this Chapter, the current situation will be discussed so a solution to the proposed problem can be constructed. This is done by first explaining the order and delivery process of the current distribution network. Then the locations of the supplier and customers are mapped. In the third section the current demand is analysed. In the fourth section, the key performance indicators and their values are discussed that function as a benchmark for the current situation

2.1 Order and delivery process

2.1.1 Inbound logistics

The consumables that are sold to customers are not produced by Company X, contrary to the steel working machines that are produced by Company X. Company X has 20 consumable suppliers all located in Europe from which consumables are ordered, after which they are stored in the warehouse located at destination X. The warehouse department runs a total stock evaluation two times a day to see if any shortages occur. After the stock evaluation, shortages are reordered from the suppliers to prevent stockouts. The location of all consumable suppliers is depicted on the map in Figure 3.

Figure 3: Supplier locations

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2.1.2 Outbound logistics

The order and delivery process consists of two phases. In the first phase, the order is received and prepared to be shipped to the customer. In the second phase, the order is picked up by the transportation company and shipped to the customer. To visualize the order and delivery process, a flow chart is made which is depicted in Figure 4 below. This flow chart is made so the bottlenecks in the delivery process can be identified. In both phases of the delivery process, delays can occur which are described in Section 1.2.1.

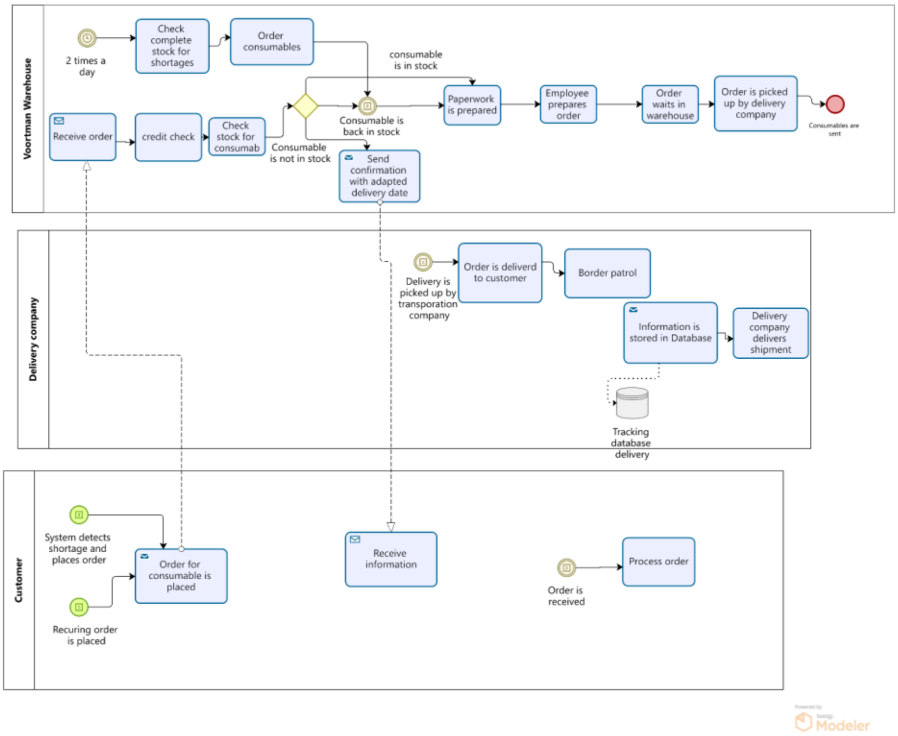

Figure 4: Process flow chart

2.1.3 Modes of transportation

Currently, orders are shipped from the branch at destination X to customers by two different transportation companies namely; DHL and UPS. UPS is mainly used for shipments inside the Benelux and DHL is used for the remaining shipments. Both transportation companies have two different shipping policies based on the desired transit time and the size of the package. DHL has Euroconnect for large pallet shipments and express for smaller packages. UPS uses standard delivery which only uses road transport and Express saver delivery which uses air transport (if faster). The packages are transported by trucks, trains, planes and boats.

2.2 Location of the current facility and customers

Currently, Company X has four branches located in four different countries. The branches are located in the Netherlands, Russia, the United States and Australia. Company X only has two storage locations from where products are being shipped to customers which are located in The Netherlands at destination X and in The United States. As some customers are located far from the current warehouse at destination X, the delivery times increase when distances are increasing. To give a better idea of where the customers are located, a heat map of the number of customers per country is depicted in Figure 5.

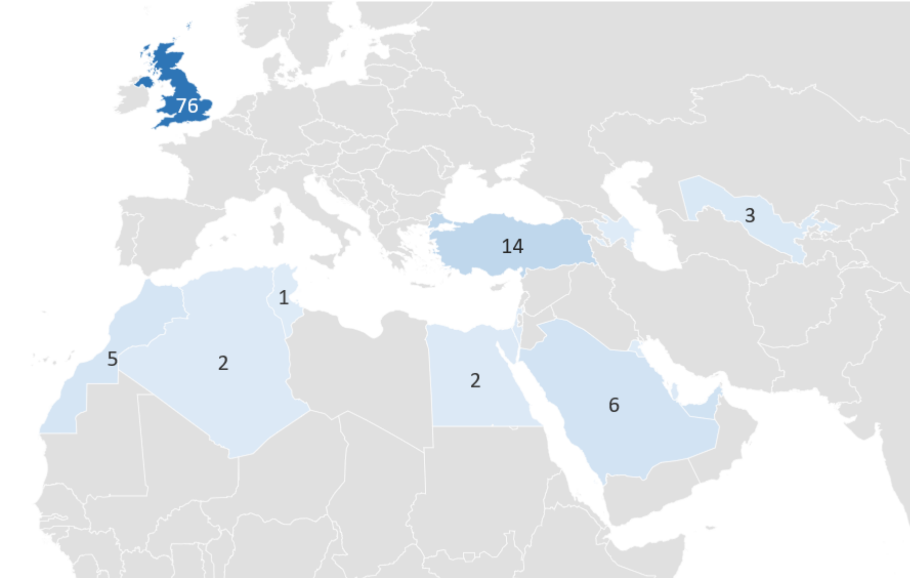

Figure 5: Number of customers per country map

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The customers in the concerned regions that ordered consumables from Company X in the past year(01/09/2021 – 01/09/2022) are mapped in Figure 6. The factory located at destination X is depicted with an orange marker.

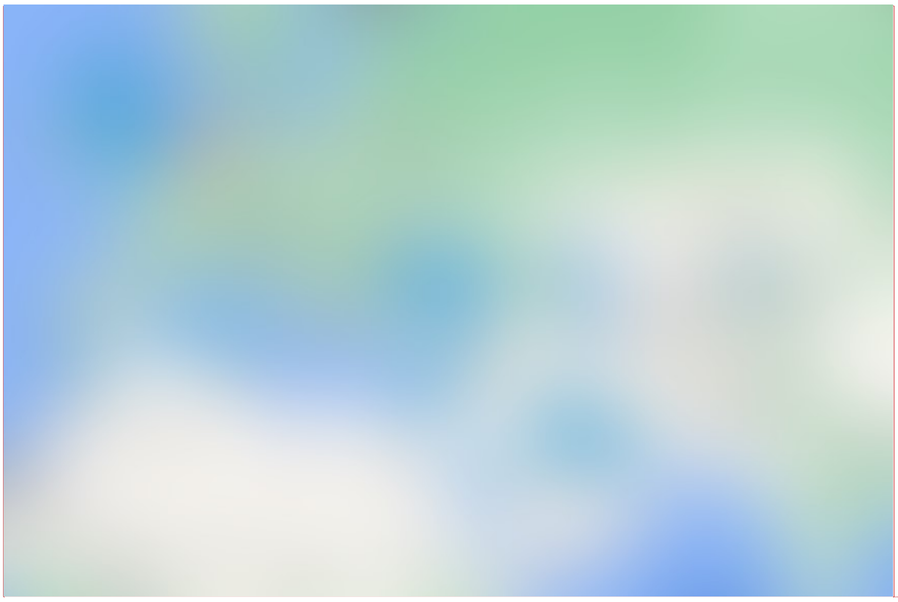

Figure 6: Map of customers

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2.3 Customer demand

To get an idea of the total growth of consumables demand in the discussed countries, a graph that visualizes the total demand per month is depicted in Figure 7 shipments. Also, a trend line that indicates the overall direction of the shipment data is given. It shows that there is an increase in demand from 110 shipments per month in July 2019 to a little over 140 shipments per month in July 2022. The data that is used to visualize the customer demand is retrieved from the database Transsmart, in which all shipments are registered.

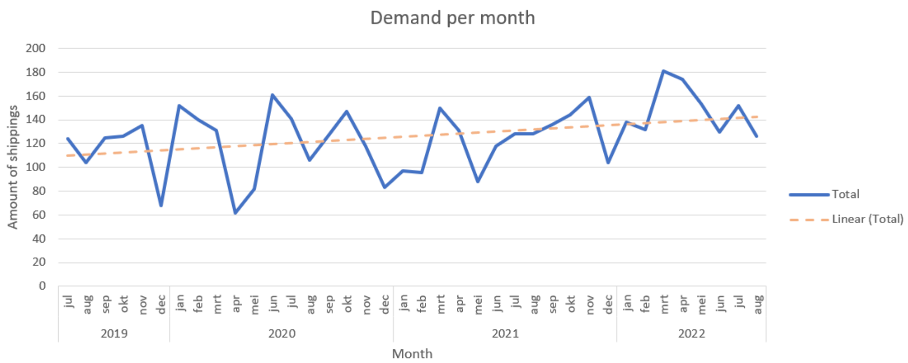

Figure 7: Total consumable demand per month

The total demand can be divided into the demand per country to get a better idea of the demand distribution over a certain region. The demand per country is visualized in a geographical map in Figure 8 expressed in the number of shipments per country. The demand is from the period 2019/9/1 - 2022/9/1

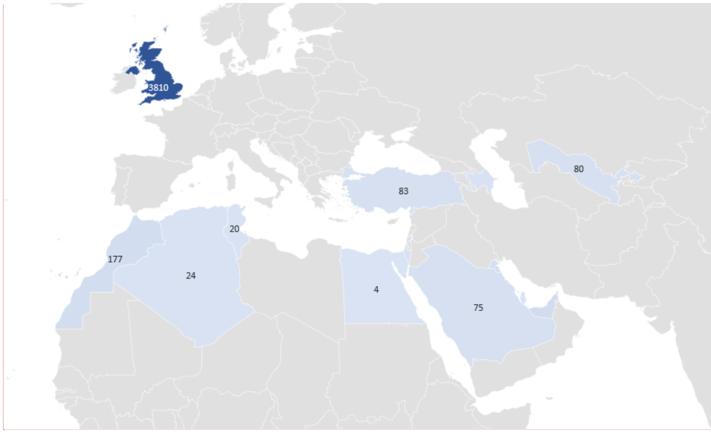

Figure 8: Number of shipments per country in the past three years

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2.4 Key performance indicators

To measure the effectiveness of the solution, key performance indicators are an important tool. Key performance indicators, also called KPIs, can quantify the effectiveness of the solution on different aspects of the problem. In consultation with Company X, the following KPIs have been constructed and can be used to assess the effectiveness of the implemented solution:

Maximum distance from the warehouse to the customer

The maximum distance to customers is chosen as a KPI so that it can be monitored whether the distance from the newly placed warehouse to the customers is not unacceptably high. Often, facility location models use an objective function that is aimed to be minimized. The objective often is to minimize costs or weighted distance added for all customers. The individual situation of all customers is therefore not taken into account and it is possible that the situation of some customers is worsened more than acceptable. This KPI is expressed in kilometres.

The average distance from warehouses to customers

In combination with the previous KPI, the average distance from the warehouse to the customer gives a good indication of whether the solution improved the distance that has to be travelled. This KPI is expressed in kilometres. The average weighted distance from warehouses to customers
The average weighted distance is the average of all weighted distances between the customers and the assigned warehouses in which the weight represents the number of shipments from the customers. The number of shipments is extracted from Transsmart.

The average weighted distance from the warehouses to customers
The weighted distance between a customer and a warehouse is calculated by multiplying the distance between those two and multiplying it by the number of shipments from that customer in the past year. Then the average is taken over all distances between the warehouses and their assigned customers. It is chosen to take the shipments of the past year so that only customers that are still ordering consumables from Company X are taken into account.

Facility renting costs per year
Next to improving the delivery time to the customers, it is important to monitor the expenses that come along with opening warehouses. A balance between decreasing delivery time and costs should be made so that the investment can be paid back in the future. This KPI is expressed in euros.

Outbound transportation costs
The costs that originate from sending the consumables from the located warehouses to the customers are the outbound transportation costs and are an important criterion when choosing the number of warehouses to build. This KPI is expressed in euros.

Total costs
To measure the total expense that is needed to rent and run the warehouses, the total cost of the solution is monitored with this KPI. This KPI is also used as a criterion when choosing the number of warehouses. This KPI is expressed in euros.

Average delivery time per country
The delivery time is a good indicator of the performance of the solution. The goal is to decrease the delivery time of most customers and therefore the average delivery time per country should decrease.

2.5 Performance of current distribution network

The KPIs that are determined in the previous section are now used to measure the performance of the current distribution network. These KPIs act as a benchmark that can be compared to the values of the KPIs in the future situation. All KPI values have been depicted with an explanation of their source or calculation method. A summary of all values is depicted in Table 3.

Maximum distance from the warehouse to the customer
KPI value: 5,108 km

All customers and their addresses have been extracted from the Excel sheet that is extracted from Transsmart. The addresses are used to retrieve the GPS coordinates which are expressed in longitudes and latitudes. An Excel tool is used to transform addresses to GPS coordinates. The GPS coordinates are then used to calculate the distance from the warehouse at destination X to the customers of Company X. The distance is calculated in Python by a library called Geopy. The customer that is located farthest away from Destination X is in the United Arab Emirates.

The average distance from warehouses to customers
KPI value: 1,523 km

The average distance from the customers in the concerned regions to the branch at destination X is calculated. The "shipment Excel sheet" with the customers and their coordinates is used to calculate the distance from every customer to Destination X. Then the average of these values is taken.

The average weighted distance from warehouses to customers
KPI value: 14,750

The average weighted distance is monitored because the warehouse should be located closer to customers with a relatively high demand. The weighted distance is calculated by multiplying the number of shipments for a customer with the distance from this customer to the warehouse.

Facility renting costs per year
KPI value: €0

At the moment there are no facility setup costs as there is no solution determined and thus no additional warehouse is utilized. This KPI is used to compare different solutions and assess if they are feasible.

Outbound transportation costs
KPI value: €327,249 per year.

The outbound transportation costs are calculated by multiplying all the weighted distances by the transportation costs per kilometre. The weighted distances represent an approximation of the total travelling distance.

Total costs
KPI value: €327,249 per year

The total costs are determined by adding the outbound transportation costs to the facility renting costs and is used as a criterion when choosing the optimal solution.

Average delivery time per country
The average delivery time per country is calculated with the shipment data in the shipment Excel sheet. The delivery time is calculated by subtracting the delivery date from the pickup date. An overview of the delivery time per country is depicted in Table 2. The delivery time is expressed in days. For the countries; Algeria, Egypt and Azerbaijan, no delivery date is available in the shipment data from the past year and therefore no delivery time can be calculated.

Country	Average delivery time(days)
Great Britain	2.9
Qatar	4.2
United Arab Emirates	4.4
Israel	5.3
Saudi Arabia	5.6
Morocco	7.8
Uzbekistan	8.3
Turkey	10.6
Kuweit	11.2
Tunisia	15.4
Algeria	NODATA
Egypt	NODATA
Azerbaijan	NODATA

Table 2: Shipment lead time

KPI	Value
Maximum distance	5,108 km
Average distance	1,523 km
Average weighted distance	14,750
Facility renting costs	€0
Outbound transportation costs	€327,249 per year
Total costs	€327,249 per year
Delivery time	4 days and 12 hours

Table 3: KPI values current situation

2.6 Conclusion

Contrary to the metal working machines, Company X does not produce the consumables. The consumables are supplied by 20 suppliers spread over Europe after which the consumables are stored in the warehouse at destination X. To measure the effectiveness of the future solution, a set of KPIs is constructed in consultation with Company X. The values of these KPIs are established for the current situation. The average distance between the warehouse at destination X and the customers is 1523 kilometres and the maximum distance between the warehouse at destination X and the customers is 5108 kilometres. The average weighted distance is 14,750. Currently, there are no setup costs because additional warehouses are not yet placed. The outbound transportation costs are €327,249 and are based on the number of shipments during the period of 09-01-2021 to 09-01-2022 and the distance from customers to the warehouse at destination X. The average delivery time per country is depicted in Table 2

3. Literature review

In the following chapter, literature is used to build a fundament for the choices made in Chapter 4. First, the role and effect of using warehouses within the supply chain are discussed to substantiate the use of warehousing as a solution for the proposed problem. The second section discusses different procurement types in warehousing. The third section describes important factors that have to be considered when a warehouse is located. Both, the second and third section are important in constructing an advise about the implementation of the future solution. The fourth section describes three main functions of warehouses that forms the bases of the warehouse type decision. The fifth section discusses different types of warehouse location models, after which more specific location models from existing literature are discussed. These are discussed to choose the model that best fits the problem of Company X

3.1 Warehouses within the supply chain

Warehouses are used to smooth out the demand and supply inequalities. It is almost never the case that production and demand are exactly the same all the time. According to Ackerman (2012), the inequality between supply and demand is mainly caused by two scenarios. In the first scenario, demand is fluctuating seasonally meaning that in one season the demand is high and in the other season, the demand is lower. The other scenario assumes that production is seasonal. Products are thus solely produced in certain periods of the year. Even if seasonal demand did not exist, demand and supply are almost never the same. Only producing for the demand that occurs would be inefficient as most production lines have some start-up costs when producing. Make-to-stock would be more profitable in this case. Demand or production fluctuations can be smoothened with the use of warehousing.

Warehouses play another important role in the supply chain of a company. A company can increase their responsiveness by increasing the number of warehouses within a certain area or (re)locating warehouses closer to customers. Increasing the number of warehouses typically decreases the average distance between customers and inventory and therefore decreases the average delivery time. This relation is visualized in Figure 9. Increasing the number of warehouses increases the setup and inventory costs but decreases the delivery time. When a company solely focuses on decreasing delivery time, the optimal solution will be locating a warehouse next to every customer. In the end, this is not a profitable investment as the facility, inventory, and inbound transportation costs will be extremely high. On the other hand, placing a single facility to serve all customers entail high delivery times and high transportation costs. Therefore, a trade-off between the number of warehouses and delivery time has to be made (Chopra & Meindl, 2016). The number of warehouses influences the transportation costs and setup costs. Namely, the transportation costs decrease and setup costs increase when a large number of warehouses is placed and vice versa.

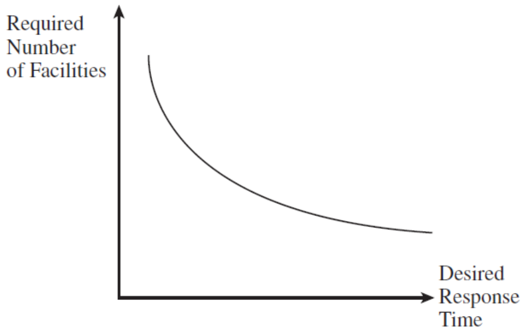

Figure 9: Relationship between response time and the number of warehouses. (Chopra & Meindl, 2016)

Companies often encounter inbound and outbound transportation costs. Inbound transportation costs are costs that are made to get goods inside storage locations and warehouses. Outbound transportation costs are costs that are made by shipping products to customers. Often, outbound costs per unit are higher than the inbound costs per unit because economies of scale can not be used in outbound transportation costs. Increasing the number of warehouses or locating them closer to the sales market decreases the outbound travelling distance. This decreases the fraction of outbound distance travelled and so the transportation costs decreases. The inbound economies of scale should be maintained in this case. Placing many warehouses decreases the inbound lot size and thus bulk-shipping cannot be applied to the full extent. Thus, placing more warehouses is profitable to a certain point. After this, the set-up costs and inbound transportation costs increase more than savings on outbound shipments. This reasoning is visualized in Figure 10 (Chopra & Meindl, 2016).

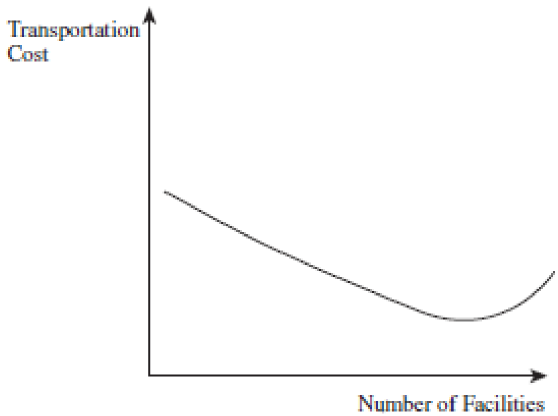

Figure 10: Relationship between the number of warehouses and transportation cost. (Chopra & Meindl, 2016)

If the goal is to maximize responsiveness, a company may decide to build more warehouses which leads to an increase in warehouse set-up costs, inventory costs, and inbound transportation costs. This decision should only be made in case a company expects the revenue to increase (due to an increase in responsiveness) more than the increase in extra costs.

3.2 Warehousing as part of the corporate strategy

According to Ackerman (2012), warehousing comes with three primary aspects; people, real estate, and equipment. The strategy that is used to manage those three is established in the corporate strategy of a company. Corporate strategy is defined as *"the pattern of decisions in a company that determines and reveals its objectives, purposes, goals and defines the range of business the company is to pursue, the kind of economic and human organization it is or tends to be and the nature of economic and noneconomic contribution it intends to make to its shareholders, employees, customers and communities"*(Foss, 1998).

Ackerman (2012) describes how a company can have different objectives and the warehousing strategy should be adapted to this strategy. A company can aim to be the largest company in the industry. The warehousing strategy should include the possibility to grow in the future. The objective can be to have the best product quality. When a company wants to aim for the lowest costs, the warehouse and transportation costs should be reduced.

Another large decision that is to be made by companies is whether to use public or private warehouses. This decision should coincide with the corporate strategy of a firm. The decision to use a public warehouse has several advantages. First, public warehousing allows a business to increase the return on assets as no large investments are made on building warehouses and purchasing machines. Instead, this capital can be invested in the main business. The second reason is increasing the efficiency of employees. The productivity increases because employees can focus more on core business tasks and less on warehousing. Companies become increasingly larger and more complicated and warehousing activities that first could be performed by non-specialized employees, should now be done by a professional company in a public warehouse. Companies that have warehousing as their main competence are more efficient and thus a cheaper option. A public warehouse handling these complicated activities is thus the third advantage (Ackerman, 2012).

Although using a public warehouse can have major positive effects on a firm's productivity, there are some downsides. First, loss of control is a large obstacle in outsourcing. All warehousing activities are done by a third party and thus information about the process and products in the warehouse are more difficult to manage and access due to communication difficulties. This communication barrier can be overcome by having a strong relationship with the warehousing company after which the full advantages of the public warehouse can be utilized (Bardi & Tracey, 1991). Ansari & Modarress (2010) describe a second downside. The requirements of some firms about, for example, the techniques that should be used in warehouses are not offered by existing warehousing companies. In this case, a company should lower their standards or use a private warehouse. Furthermore, integrating the information systems of both parties can be a challenging and time-consuming mission. The fourth obstacle is the possibility of large demand increases that can not be facilitated by the concerned warehousing company. In this case, it would be more efficient to invest in a private warehousing department right away instead of first investing in a public warehouse.

3.3 Important facility location factors

When choosing a location for a warehouse, many criteria are important to consider so the optimal location can be determined. In this part of the literature research, all important criteria are discussed. Locating a facility can have a long-term impact on the company and its performance. Reversing a location decision is very hard as the warehouses cannot be replaced or shut down without having large shut-down costs (Chopra & Meindl, 2016). Singh et al. (2018) propose various criteria when selecting a location for a warehouse, which are discussed below.

Accessible infrastructure

The first important criterion is the presence of proper infrastructure near the warehouse. A road network, sea port, airports and railway stations should be in close proximity of the warehouse so the delivery costs and delivery times can stay low. Also, infrastructure that provides electricity and water is required so the warehouse can function properly.

Laws and regulations

The existence of laws and rules in the country of location of the warehouse should be in favour of the company. The laws and rules should allow the company to build or rent the warehouse cheaply and easily. Costs of land and materials should be low so the setup costs for a warehouse are low. Also, tax rates in the region where the warehouse is placed should be as low as possible. Incentives that are given by the government to stimulate investments in a certain region can lower the set-up costs of a warehouse which lowers the total costs. Furthermore, the relations of the country where the facility is located with surrounding countries should be well maintained so that shipments can cross the border without complications such as high border patrol times.

Stable political situation

It is important that the warehouse is located in a country where no political disruptions are present. If a country is in conflict with another country, there is a possibility that a future war will disrupt the supply chain and no products can be delivered to the customers

Expansion possibilities

Expansion should be allowed by the market in which the warehouse is located. If there are large growth markets with high demand close to the warehouse, the company can expand easily in those regions. Demand forecasting can be used to assess the growth opportunities of certain countries or regions. Another prerequisite is the possibility to expand within the warehouse. When the demand is rising, it should be easy to increase the inventory in the warehouse.

Distance to customers

The distance from the warehouse to the customers should be minimized to minimize the transportation cost and increase responsiveness by lowering the delivery time. Low transportation costs ensure a more profitable warehouse which is desirable.

3.4 Warehouse functions

Langevin & Riopel (2005) define a distribution centre as a specific type of warehouse. Warehouses only store products and goods without adding any value to them. Distribution centres on the contrary perform activities such as order-picking, order assembly and shipping. A distribution centre is a type of warehouse where there is no or limited storage of goods. If any storage exists in distribution centres, it often consists of high-demand items. Nowadays, the terms distribution centre and warehouse are used interchangeably. Frazelle (2016) refers to the term distribution warehouse in which both larger amounts of inventory are stored and distribution activities are performed.

3.4.1 Make-bulk/break-bulk consolidation centre

Make-bulk and break-bulk are two functions that take place in a distribution centre. In break-bulk centres, large bulk shipments are broken down into smaller parts and then combined into customer-specific outbound shipments. The break-bulk centres also perform analysis on which orders should be combined to ship them as efficiently as possible. Make-bulk means combining multiple smaller shipments into a large bulk shipment (Langevin & Riopel, 2005). A visualization of a make-bulk and break-bulk centre is depicted in Figures 34 and 35 in Appendix A.

3.4.2 Cross docking centre

Cross docking centres receive products, then couple the products that need to go to the same destination and immediately ships the cargo without storing it in a warehouse. The main goal of cross-docking is changing the type of conveyance, for example from boat to truck (Langevin & Riopel, 2005). The difference between a cross-docking and a break-bulk or make-bulk is that cross-docking does not change anything about the size of the shipment.

3.4.3 Product-fulfilment centre

The product-fulfilment centre's main function is to react adequately to orders from customers. The centre handles product orders by picking them and also takes care of customer service. The orders that are handled by a product-fulfilment centre are relatively small. The payments of customers are also handled by this type of distribution centre. Another important feature is the presence of inventory at the centre which is fundamental in meeting customer demand adequately.

3.5 Location models

Before elaborating on specific models, different types of models will be explained after which several specific models are discussed in more detail. Daskin (2008) classifies the facility location problem into four different categories, namely; analytic models, network models, continuous models and discrete models.

3.5.1 Types of models

Analytic models

Analytic models assume that the demand is distributed continuously over an area with customers. The warehouses have to be located in this area to serve the demand. The analytic models can be solved with the use of mathematics and no heuristics are required (Daskin, 2008).

Continuous models

The continuous space location problem is the second category and chooses the optimal location from a selected geographical space. Thus, the number of possible facility locations is infinite, although the demand points are discrete in contrast to the analytic models. The advantage of a continuous model is being able to freely choose the optimal location solution while not being bound by the discrete set of possible facility locations. The Weber problem is a continuous location model and assumes that demands occur at discrete points. The objective of a Weber problem is to find a location (X,Y) in which X and Y are the coordinates of the optimal location in a plane. This problem aims to find a single warehouse and not multiple warehouses. The Weber model minimizes the distance that is weighted by the demand of each demand point (Daskin, 2008).

Network models

According to Daskin (2008), network models propose a network of nodes and links on which the demand points and warehouses are located. Typically such models can be visualized by trees. The demands arise at the nodes of the tree and warehouses can be located everywhere on the tree. The objective here is also to minimize the total distance between the demand point and the facility weighted by the demand of that point. Goldman (1971) solved such a network model.

Discrete models

Discrete location problems are the last class within facility location models. In this type, a discrete set of warehouse location options is chosen from which the optimal location(s) are chosen with the use of a model. The demand points are also in a discrete set. Discrete models can be further categorized by; covering-based models, median-based models and other models. Covering-based models assume that every demand point should be within a minimum range of the facility because there is some time constraint on the demand to be fulfilled. Covering models are often used in organizations where strict rules about distances between demand and service points apply. Possible applications of covering models are the placement of AEDs in certain demand areas proposed by Demirtas (2016), and minimizing the number of new fire station locations that cover a certain demand area proposed by Aktaş et al. (2013). Set covering models are a category within the covering-based models and aim to locate the minimal number of sites to cover all demands. Max covering models, the second category within covering-based models, aims to cover the maximum number of demand points with predefined p sites. The P-center problem, a third category inside the covering-based models, aims to locate p sites that cover all demands with a minimal coverage distance. Median-based models are the second category within the discrete models. A p-median model, which is inside the median-based category, aims to minimize the average (weighted) distances. The second type is a fixed-charge model which are often applied to problems where minimizing costs is the objective. The third type of discrete models are models that can not be placed in the covering-based and median-based models. An example is the p-dispersion model in which the distance between warehouses is maximized. P-dispersion models are often used in situations where the inventory stored in the facility is explosive and thus should be located far away from each other. A visualisation of the different discrete model categories is depicted below (Daskin, 2008).

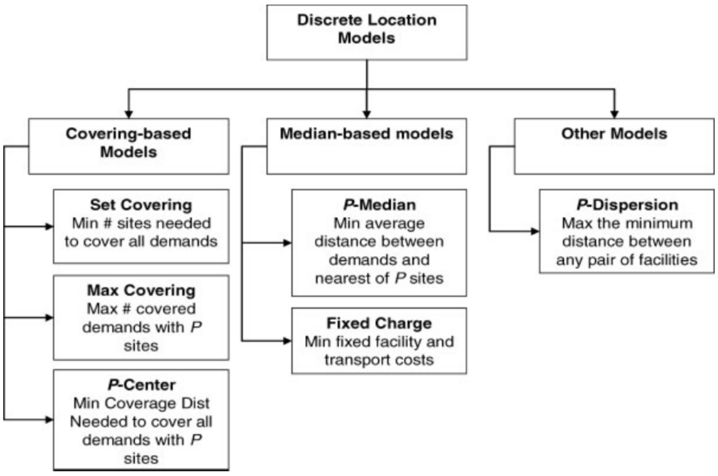

Figure 11: Chart of discrete location model types (Daskin, 2008).

Other model characteristics

The type of problem can even be further defined by other characteristics. Klose & Drexl (2005) state several characteristics a model can have.

The objective of a function can differ between minmax and minsum types. A minsum model aims to minimize the average weighted distances between warehouses and customers. A minmax model aims to minimize the maximum distance between warehouses and customers.

The second model characteristic is the capacity of a warehouse. Capacity-constrained models limit the number of products that can be stored in a warehouse. In other words, the amount of demand from customers that can be fulfilled by one warehouse is limited by the capacity of that warehouse.

Single-stage models assume that the goods only flow from one point to the other which is called a stage. In multiple-stage models, goods flow through multiple stages in a given sequence

Single-product models use the same demand, costs, and capacity for all products and thus multiple different products can be simplified into one product in the model. Products that do not share the same characteristics have a different effect on the optimal location of the facility and thus a multi-product model should be used.

Static models determine the optimal solution based on the assumption that transportation costs and customer demand stays the same over time. This often is not the case and thus dynamic models can be used to overcome changes in parameter values. Dynamic models use multiple evaluation stages in which warehouses can be closed and opened. With the use of dynamic models, the extra costs caused by opening or closing a facility are weighted against the extra benefits in the form of lower transportation costs.

3.5.2 Specific models

P-median model

Christofides & Beasley (1982) propose the P-median model. The model uses a discrete set of possible warehouse locations and a discrete set of demand points. In this type of model, the number of warehouses, p, to be located, is predefined. This model does not account for any possible facility set-up costs and transportation costs. The objective of a P-median model is to minimize the weighted distances when locating p warehouses.

Uncapacitated, single-stage model

Klose & Drexl (2005) present a model to solve a facility location problem with fixed setup costs. The model tries to locate one or more warehouses so the sum of the fixed setup costs and variable costs is minimized. In contrast to the previous model, this model minimizes the total costs instead of minimizing the weighted distances. The model that is proposed is fairly simple, as it only considers two types of costs: costs of locating a warehouse at a certain point and the shipping costs from the warehouses to the customers. This model also uses a discrete set of possible facility points and demand points.

Multi-commodity model

Warszawski (1973) proposed a facility location model that includes multiple products, this means that there has to be one supply centre per product. The model has the same structure as the uncapacitated single-stage model but the multiple-product feature has been added with the use of extra variables.

Multi-stage model

Graves (1974) proposes a multi-stage model in which there are multiple layers of warehouses and production facilities of which the optimal locations have to be determined. The products have a certain sequence in which they pass through the several layers. These models can be used when a product needs multiple modifications that are done in multiple different places, after which the products need to be stored in a warehouse.

Dynamic model

Facility location decisions are long-term decisions that are expensive to reverse. The location of warehouses is often based on the demand distribution of the past years. It is possible that in the years after building the facility, the demand distribution changes and thus that the current location is not the most optimal anymore. Dynamic models account for the possibility of relocating warehouses. In these models, there is an open and close option for every facility in every period. A dynamic model with corresponding constraints is proposed by Erlenkotter (1981).

Stochastic model

The data that is used in models to determine the optimal facility location often is not entirely accurate and is subject to some probability. To account for the possibility of the data not being 100 per cent true, stochastic or probabilistic models are used. Probabilistic models can be used in case demands and/or travel costs are stochastic (Mirchandani et al., 1985). Probabilistic models need large amounts of observed data before a theoretical distribution can be applied to for example the demand of customers. Often these amounts of data are not available and thus such models are hard to implement.

Multi-criteria model

A more sophisticated but complicated model is proposed by Izdebski et al.(2018). This model also uses an objective function in the same form as the uncapacitated model described by Klose & Drexl

(2005) but a lot of additional criteria are incorporated into the model. Next to the fixed warehouse set-up costs and variable transportation costs, the model of Izdebski et al. (2018) consider variables such as vehicle capacity, unit costs of fuel, storage costs, taxes in the place of the warehouse's location, the running costs of each warehouse etc. Such a model can give a more accurate optimal solution for the location of a warehouse. The pitfall of having such a detailed model, is that a lot of information is needed and therefore the change of making a mistake in assuming or collecting data is larger. Furthermore, collecting such location-specific data is very time consuming.

3.6 Conclusion

Warehouses are used to store products in case the production does not perfectly meet the demand. Warehouses can also increase the responsiveness to customers when the location is analysed thoroughly. There are different types of warehouses each performing different activities. Examples are: make-bulk, break-bulk, cross-docking and product-fulfilment centres. Break-bulk and make-bulk centres only change the size of the shipment while cross-docking centres change the type of conveyance. A product fulfilment centre handles a lot more activities such as order picking, customer service, inventory management and return management. To evaluate the number of warehouses and their location within a distribution network, optimization models can be used. Different models have been discussed. The two main categories are; median-based and covering-based models. Models that can not be classified fall inside the category 'others'. Models within these categories take into account different aspects within problems. Models can take into account the capacity of the warehouse, multiple stages in a distribution network, multiple products, stochastic demand, multi periods and a variety of other aspects.

4. Solution design

The following chapter first describes the overall setup of the solution by looking at the shipment location, the warehouse setup and the shipping policy. In the second section, the model choice is substantiated and a final model decision is made. In the third section, the model and the constraints are discussed.

4.1 Various solutions

4.1.1 Shipment location

Direct shipments from suppliers

One of the solutions for the high delivery time can be sending the ordered consumables directly from the suppliers to the customers. This will decrease the distance from storage to the customer and therefore decrease the delivery time. This would also decrease the transportation costs as the consumables are not first shipped to the Netherlands and then shipped to the customers. However, this solution is not feasible because most of the suppliers are not able to prepare invoices and pack orders. Secondly, customers don't want their orders to be broken into multiple shipments. Furthermore, supplying directly from the suppliers would complicate the supply chain more because the origin of the consumables is not the same. Often, orders from customers contain different consumables from different suppliers. A fourth reason is that the distance from the suppliers to customers is still large which still results in long delivery times

Shipment from new storage location/warehouse

The second possible solution is to build warehouses that can be used as storage locations from which the orders are shipped to customers. This would decrease the distance from the storage location to customers drastically which then decreases the delivery time. Furthermore, this solution will increase the fraction of the distance that is travelled as an inbound shipment and decrease the fraction of the distance that is travelled as an outbound shipment. The inbound costs are less expensive per product than the outbound shipments and thus the total shipment costs will decrease. The inventory costs will increase as a result of this solution because more safety stock must be utilized due to multiple stock locations being used.

The solution of a new storage location is chosen as the final solution because it decreases the distance from the stock to the customers to a greater extent than the first solution. Furthermore, the outbound transportation cost decreases. The amount of time shipments spent at border patrol also decreases for some customers because when products are shipped within a country, no border patrol is encountered in this case. Implementing this solution needs a model to evaluate the optimal number of warehouses and their optimal locations. The selection of a model is discussed in Section 4.2.

4.1.2 Warehouse setup

A decision to make, is whether to build a private warehouse, rent a private warehouse or rent a public warehouse

Building a private warehouse

Building a warehouse entails large setup costs which make total costs higher. Building a warehouse also means that employees of Company X have to shift their attention to warehousing activities and less focus is laid on main activities that can lead to company growth. Furthermore, less assets are available when a large investment is made. This money will then not be available for investments within the main activities of Company X such as research and development. Furthermore, Company X first wants to test the solution before investing large amounts of money in building warehouses. Therefore, this solution is not chosen.

Rent a private warehouse

A second option is renting a private warehouse. This solution does not bring high investment costs and thus other investments regarding the main activities of Company X can be made. However, Company X still has to take care of warehousing activities such as customer service, order picking and retour management. Furthermore, Company X is a growing company with an increasingly complicated supply chain. Outsourcing these complicated tasks to a third party is more convenient.

Rent a public warehouse

Renting a public warehouse so the warehouse activities are outsourced has several advantages as described in the literature review in Section 3.2. The main reason is that the employees can focus their attention on the main activities of the company. The second reason is the increase in return on assets as no large investments have to be made. Based on these advantages, it is chosen to rent a public warehouse and outsource the warehouse activities.

Type of warehouse

In the case of this research, large bulk shipments from the warehouse at destination X should be broken down into smaller shipments. However, a break-bulk centre does not perform any other activities such as customer service, order picking and inventory management. Therefore, a break-bulk centre does not solve the problem that is faced in this research. A cross-docking centre also does not solve the problem that is faced in this research because this type of warehouse has no storage. Storage near the customers is necessary to adequately react to customer demand to lower the delivery time. Furthermore, a cross-docking centre does not break large shipments into smaller shipments which is crucial in making customer-specific orders. The product fulfilment centre meets all requirements of a facility type that is needed to solve the problem. This type of facility handles order picking, customer services, inventory management and customer returns. These are all prerequisites for a warehouse so a lower delivery time can be achieved. Therefore, this type of centre is chosen as the type of warehouse to solve the proposed problem.

4.1.3 Shipping policy

Currently, the consumable orders are prepared in the warehouse at destination X. Every order is packed in its own box or pallet and is shipped to the customer. In the future situation, the consumables would be sent to the new warehouse locations in bulk regularly. A large fraction of the distance that must be travelled from the warehouse at destination X to the customers results in inbound shipping costs, which are often lower due to the use of economies of scale. The restock frequency and the order quantity should be determined in future research so that the warehouse solution can be implemented.

4.2 Model choice

In this section, a table with the advantages and disadvantages of all models is given based on the literature of Section 3.4.2.

Model name	Advantages	Disadvantages
P-median (Christofides & Beasley, 1982)	- Small amount of data is needed compared to other models - The objective is minimizing the distances	- No costs related to transportation or set-up - The number of facility locations must be previously defined - The capacity constraint is not included
Uncapacitated model presented by Klose & Drexl 2005)		- Model is more complicated - More data is needed within the model (transportation costs) - Objective function is to minimize costs
Multi-commodity model (Warszawski, 1973)	- The model takes into account different parameter values for different commodities/products such as differing demand	- Model is more complicated - More data is needed within the model - Objective function is to minimize costs
Multi-stage model (Graves, 1974)	- The model takes into account different hierarchical layers of the model - The model takes into account costs for inbound transportation	- Model is more complicated - Model is harder to solve with exact methods - Objective function is to minimize costs
Dynamic model (Erlenkotter, 1981)	- The model takes into account the possibility to open and close warehouses in different periods	- Demand distributions/predictions are needed in every period which are currently not present at Company X - Model is more complicated - Objective function is to minimize costs
Stochastic model (Mirchandani et al., 1985).	- The model considers the possibility for deferring demand	- Hard to fit a theoretical distribution on the empirical data as the data set must be very large. This data is not available at Company X - Objective function is to minimize costs
Multi-criteria model (Izdebski et al. , 2018)	- The model considers a lot of criteria and thus	- The model is overcomplicated and a

	a very accurate location will be determined.	lot of data has to be collected before the model can be used. - Objective function is to minimize costs

Table 4: Model advantages and disadvantages

The model that is used in this research is the P-median model because the goal of the research is to decrease the delivery time by decreasing the weighted distances and not the total costs. The P-median model is relatively simple and easy to compute with exact solving methods. Furthermore, a relatively small amount of data is needed to solve this problem. The consumable distribution network of Company X does have two stages in the supply chain namely the two periods of the lead time described earlier. The multi-stage model would thus be an appropriate model to use in this research. However, it is aimed to decrease the distances between demand points and supply points and not the total costs of placing warehouses, thus the multiple stage aspect is not included. Multicommodity models assume that there are multiple plants that send multiple products to one or more warehouses. Company X only uses one warehouse that is located at destination X to send products to multiple warehouses and thus no multiple commodity model is needed. The capacity of the warehouse is not included in this model because specific warehouses are not evaluated, this must be considered in future research. A dynamic model is not used because no data on future demand is available and thus decisions regarding opening and closing warehouses are not possible. Because of the absence of data on future demand, a stochastic model is also not used.

4.3 The model

The p-median model uses an objective function which aims to minimize the sum of weighted distances between the warehouses and the assigned customers. The distances from the customer to the warehouse are weighted by the number of shipments that are sent to this customer. This ensures that the optimal warehouse location is closer to larger customers and less close to smaller customers. This is desired because of two reasons. Larger customers are more important to satisfy as they cause a larger part of the revenue. Secondly, placing warehouses closer to larger customers decreases the transportation costs even more than when the weight is not considered. The P-median model is mathematically described as follows:

$$\min \sum_{k \in K} \sum_{j \in J} w_k \, d_{jk} z_{jk}$$

Where:

w_k : is the weight (reflecting the demand) of customer k

d_{jk} : is the distance from warehouse j to customer k expressed in kilometres

z_{jk} : is a binary decision variable that turns 1 if customer k is assigned to warehouse j and 0 otherwise

y_j : is a binary variable that turns 1 if facility j is opened and 0 otherwise.

K : is the set of customers

J : is the set of possible facility locations

p: is the desired number of warehouses

With constraints:

$$\sum_{j\in J} Z_{jk} = 1 \quad \forall k \in K \qquad (1)$$

$$Z_{jk} - Y_j \leq 0 \ \forall k \in K, j \in J \qquad (2)$$

$$\sum_{j\in J} Y_j = p \qquad (3)$$

$$Z_{jk}, Y_j \in \{0,1\} \quad \forall j \in J, \quad k \in K \qquad (4)$$

$$y_0 = 1 \qquad (5)$$

Where constraint (1) ensures that only one warehouse is assigned to every customer. Constraint (2) ensures that if customer k is supplied from warehouse j, warehouse j must be open. Constraint (3) ensures that exactly p warehouses are located. Constraint (4) indicates that Z_{jk} and Y_j are binary variables. Constraint (5) ensures that the warehouse at destination X is always utilized, as warehouse 0 is the warehouse at destination X.

4.4 Conclusion

The solution to the proposed problem is in the form of locating one or multiple warehouses on a map, therefore a location model is needed. The location models discussed in Section 4.3.2 have different advantages and disadvantages. After considering the advantages and disadvantages of the models, the p-median model is chosen as the model for the optimal solution. The main reason being the objective function that measures the weighted distances instead of the costs, as the main goal of this research is to shorten the delivery time by decreasing the distance between customers and the warehouse(s).

5. Experiment design
The following chapter provides an explanation of the experiment design. First, it is explained how the model is solved and what techniques are used. Then the variation of the parameters is used to explain the different experiments. In the data collection section, it is explained how the data is collected and how it is prepared to be usable in the model.

5.1 Model setup
The p-median model that is discussed in Section 4.2 is programmed in Python version 3.9.12. To find the optimal location, the P-median model has to be run for every possible k (customer) and j (warehouse). This research includes 189 customers of Company X and a maximum of 5330 possible warehouses that originate from the constructed grids which is explained later in this section. Calculating every possible distance between customers and warehouses by hand is extremely time consuming. Therefore, Python is used to program the model and the solver Gurobi is used to solve the model. Gurobi is a solver that optimizes models for all sorts of applications such as logistics, healthcare and financial services. First, the objective function with the corresponding constraints is initialized. Then the data is loaded from the Excel sheets. Information about data collection can be found in Section 5.2. The p-median model uses a discrete set of possible facility location points. This means that preliminary work has to be executed to find suitable facility locations on the map. This project covers a large surface area of roughly 10 thousand by 5 thousand kilometres. Finding locations on such a large area is an extensive amount of work. Therefore, a grid with equal distanced points is made where the points act as possible warehouse locations. A visualization of one of the grids used is depicted in Figure 12. The program QGIS is used to visualize the warehouse grid and the customers. Excel sheets with coordinates are loaded into QGIS and the points are displayed on a map. Some grid points are located in the ocean in every experiment. It is very time consuming to remove all those points, so it is chosen to run every experiment including the points in the ocean to see where the optimal location lies. If it is concluded that the final optimal location is in the ocean, the points that are located in the ocean should be removed.

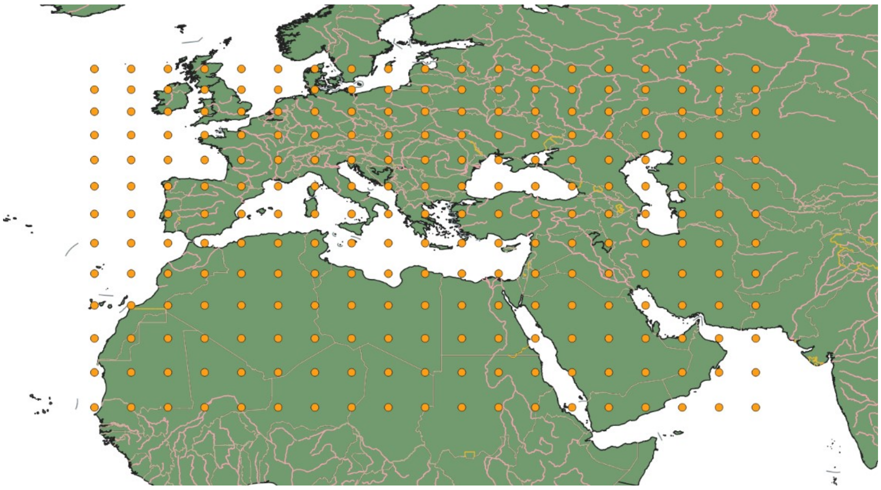

Figure 12: Grid spanning all regions

5.2 Experiments

5.2.1 Experiment parameters

Number of warehouses initialization

The p-median model calculates the optimal location of a predefined number of warehouses which is initialized with the variable p. In consultation with Company X, it is decided that the model is executed 6 times. This means that the model is executed for 1 to 6 warehouses. The first experiment only includes the warehouse at destination X and thus gives the KPI values of the current situation. With every experiment, the total costs are divided into inbound delivery costs, outbound delivery costs and renting costs and calculated together with important KPIs so a balance between the delivery time performance improvement and the costs can be made.

Grid configuration

To get a better understanding of how the model locates the warehouses without using prior knowledge, first a grid that covers the whole region is used to compute the optimal locations. The distance between the grid points is 500 km in this first phase so that the runtime of every experiment is below 30 seconds. This upper bound has been used so it is easier to experiment with different parameters. Using a grid with a smaller distance between grid points increases the number of combinations between customers and warehouses which increases the run time of experiments. Several experiments with the distance between grid points are executed in Table 8 in Appendix B and it can be seen that the run time drops below 30 seconds when using a distance of 500 kilometres. Then, in the second phase, the grid is split up into different parts based on the optimal number of warehouses and the assignment of customers to warehouses that is concluded from the first phase. In the second phase, the grid point distance can be decreased to 50 kilometres so a more precise location can be established.

5.2.2 Experiment phases

Different experiments are executed to see how the location solution varies with different model parameters. Different combinations with the grid point distance, various grids and the number of warehouses are executed. All experiments are depicted in Table 5. The experiments are divided into two phases that are described in the next section.

Experiment number	Grids used(grids)	Grid point distance (km)	Number of warehouses(P)
1	1 grid	500 (figure 12)	1
2	1 grid	500	2
3	1 grid	500	3
4	1 grid	500	4
5	1 grid	500	5
6	1 grid	500	6
7	1 grid(Great Britain)	50	2
8	1 grid(Middle East)	50	2

Table 5: Warehouse location experiments

Experimentation phase

The first phase tries to find clusters of customers with corresponding warehouses with a single, relatively coarse grid. The distance between grid points is 500 kilometres to keep the runtime of the experiments reasonable. In this first phase, an estimation about the number of warehouses and the assigned customers is made, depending on the KPI values of the different experiments.

Relocation phase

Now that an intermediate decision about the number of warehouses and the assigned customers is made, a more accurate location for every warehouse can be found. This is done by constructing a grid with more grid points for every cluster of customers. The model is executed with a p-value of two for every cluster of customers. A p-value of two is chosen because the warehouse at destination X stays utilized and it can be possible that customers are still assigned to the warehouse at destination X due to proximity to current customers.

5.3 Data collection and preparation

The data that is needed to execute the model is collected in this section.

Demand (W_k)

The shipment data from 1/9/2021 to 1/9/2022 is downloaded from Transsmart and imported into an Excel sheet. In the experimentation phase, the coordinates of all customers are loaded into a separate Excel file with the corresponding demand. In the relocation phase, the Excel sheet is split into three sheets including the different clusters with corresponding coordinates and demands. The clusters originate from the intermediate decision about the number of warehouses and the assigned customers. A more elaborate explanation about the clusters is given in Section 6.3. These sheets are then loaded into Python so the weighted distance between every warehouse and the customers can be calculated.

Distance (d_{jk})

First, all unique addresses with corresponding countries and cities are extracted from the sales Excel sheet. These addresses are loaded into an Excel file that transforms the addresses into coordinate points with a latitude and longitude. This process is called geocoding. A geocoding Excel file is downloaded from the internet and used to extract the coordinates from the addresses. A test with a small sample is executed to test if the correct coordinates were extracted from the addresses. A further elaboration on this test is given in Section 7.1. The distance between the customers and the possible warehouse is then calculated with a Python library called Geopy which calculates the shortest distance between two points. In combination with the weights of every customer, the weighted distances are calculated by multiplying the distance from facility j to customer k by its demand which are then loaded into a Python dictionary where the combination (j,k) functions as a key for the corresponding weighted distance. The validation of the Geopy distance calculator is discussed in Section 7.2.

Grid points

The grid points are made with the create_grid() function. This function needs four parameters namely; the lower left corner and the upper right corner of the grid both depicted in latitude and longitude, the file in which the grid points should be stored and the distance between the grid points. The lower left and upper right grid corners are extracted from QGIS and chosen such that every intended customer is included.

Outbound transportation costs:
The inbound transportation costs are calculated with the use of the transportation costs table provided by DHL. Company X uses multiple transportation companies for the consumable deliveries. However, to simplify the calculations, only the transportation costs of DHL are used. The transportation costs are based on the weight of a shipment and the zone to which it is shipped. A table in which the transportation costs per weight and destination zone is depicted is used. The average weight of the shipments of the past year is calculated. The corresponding row in the DHL table is found and the average shipment cost is calculated. The cost per shipment is then divided by the average distance of the shipments of the last year. A shipment cost of 0.118 euros per kilometre is used to calculate the total shipping costs in every experiment. The shipping cost is a rough estimate and is likely to differ from this value. The transportation costs are calculated by multiplying the price per kilometre by the weighted distance. The weighted distance represents how many times a truck has to drive to the customers.

Renting costs
Estimating the warehouse renting costs is difficult because it is not clear what the size of the warehouses will be. The size of the warehouse is dependent on the stock and the safety stock within the warehouses. This research does not cover those aspects and thus the renting costs used in this research are merely rough estimations. In consultation with Company X, it is estimated that every additional warehouse costs €70,000 per year including renting and handling costs. This follows from the assumption that warehouses with a surface of 500 m^2 and a square meter price of €140 are needed.

5.4 Conclusion
To find the optimal warehouse location the model is programmed in Python with the use of the library Gurobi, a solver that can be used to solve all sorts of optimization problems. Two phases are used to find the optimal warehouse location. The first phase uses a coarse grid with a distance of 500 kilometres between the grid points. In this phase, 6 experiments with a p-value of 1 to 6 are executed. The grid is made with a code that is programmed in Python. In every experiment, the KPI values are calculated so the optimal number of warehouse locations can be found. From the first experiment phase, it is also clear what customers are assigned to what warehouses and what the semi-optimal location is. The second phase relocates the warehouses with a finer grid with a distance of 50 kilometres between the grid points. The warehouse location that follows from this phase is a more accurate representation of the optimal warehouse location.

6. Results

In this chapter, the results of the experiments described in Section 5.2.2 are presented. First, a grid with a distance of 500 kilometres is used on the complete map including all customers in Great Britain, The Middle East and North Africa as explained in Section 5.2.1. In the following sections, all experiments from phases one and two are presented. The stars that are mapped represent the optimal locations established by the model. The dots with corresponding colours are customers that are assigned to this warehouse. The model decision depends exclusively on the weighted average distances between customers and possible warehouse locations. Factors such as political disruptions, the absence of infrastructure or geological obstacles are not considered by the model. The KPI values of every experiment are depicted below the experiment visualization. The KPI values are also graphed with respect to the number of warehouses.

6.1. Current situation (locate 1 warehouse)

Figure 13: Current situation

Average distance: 1,523 kilometres
Maximum distance: 5,108 kilometres
Average weighted distances: 14,750
Renting costs per year: €0 per year
Outbound transportation costs starting situation: €327,248 per year
Total costs: €327,248 per year

6.2 Experiment phase

6.2.1 Locate 2 warehouses

In the first experiment, the parameter p, the desired number of warehouses, has the value 2. The model established a warehouse location in the middle east which is shown in Figure 14 with the red star. The warehouse is located in the middle of the Persian Gulf. This issue is addressed in phase 2, where a more specific warehouse location is found. The warehouse at destination X also stays utilized. The customers are assigned to the warehouse that is closest. The KPIs corresponding to this experiment are listed below.

Figure 14: Locate two warehouses

KPI values:
Maximum distance: 2,390 kilometres
Average distance: 884 kilometres
Average weighted distances: 9,777
Renting costs: €70,000 per year
Outbound transportation costs: €216,926 per year
Total costs €286,926 per year

6.2.2 Locate 3 warehouses

In the second experiment, the model parameter P has the value 3. An extra warehouse in the middle part of Great Britain is identified. Customers that are located in the lower part of Great Britain are assigned to the warehouse at destination X. Assigning the customers that are located in the lower part of Great Britain is illogical because an ocean is considered as an obstacle when shipping the consumables. The warehouse is also located in water, which is addressed together with the other specified issues in phase 2 when a more specific location is found for the warehouses.

Figure 15: Locate three warehouses

KPI values:
Maximum distance: 2,362 kilometres
Average distance: 573 kilometres
Average weighted distances: 4,879
Renting costs: €140,000 per year
Outbound transportation costs: €108,253 per year
Total costs: €248,253 per year

6.2.3 Locate 4 warehouses

When using a P of 4, the model locates an extra warehouse in the upper part of North Africa. The location of this warehouse is unusual as it is located below all customers instead of locating in between the customers. This result is attributable to the coarse grid and is solved when a finer grid is used in phase 2.

Figure 16: Locate four warehouses

KPI values:

Maximum distance: 2,293 kilometres
Average distance: 490 kilometres
Average weighted distances: 3,997
Renting costs: €210,000 per year
Outbound transportation costs: €88,682 per year
Total costs: €298,682 per year

6.2.4 Locate 5 warehouses

In the fourth experiment, with a p-value of 5, the warehouse in the Persian Gulf is removed and two new warehouses are located in Jordan and Iran.

Figure 17: Locate 5 warehouses

KPI values:

Maximum distance : 1,997 kilometres
Average distance: 372 kilometres
Average weighted distances new situation: 3,366
Renting costs: €280,000 per year
Outbound transportation costs new situation: €74,677 per year
Total transportation costs: €74,677 per year
Total costs: €354,677 per year

6.2.5 Locate 6 warehouses

The fifth experiment shows that the model locates an extra warehouse in Great Britain. Great Britain has a large number of high-demand customers and therefore the weighted distance is large. The new warehouse is located in the lower part of Great Britain and is visualized in Figure 18 and Figure 19.

Figure 18: Locate 6 warehouses

Figure 19: Locate 6 warehouses(Zoom-in)

KPI values:
Maximum distance: 1,997 Kilometres
Average distance: 341 Kilometres
Average weighted distance: 3,055
Renting costs: €350,000
Outbound transportation costs: €67,791 per year
Total costs: €417,791 per year

6.3 KPI analysis and intermediate decision:

After experimenting with different P values, the KPI values of the experiments are compared. In Figure 20 the P value is plotted against the average distance. The decrease in average distance decreases with every additional warehouse that is located. Figure 21 shows a plot of the weighted average distance against the number of warehouses. Figure 22 depicts the maximum distance with respect to the p-values. Figure 23 shows the transportation costs with respect to the number of warehouses located. Figure 24 depicts the savings on transportation costs and the increase in renting costs due to utilizing different numbers of warehouses. Figure 25 depicts the total costs per number of warehouses.

After analysing the KPI values per warehouse with Company X, an intermediate decision can be made and it is established that 2 warehouses will be located due to several reasons. From Figure 20 and Figure 21 it can be concluded that the decrease in average distance average weighted distance is minimal when locating more than two warehouses. Also seen in Figure 22, the maximum distance to customers decreases steeply when building one warehouse, after which the decrease is minimal when locating three or more warehouses.

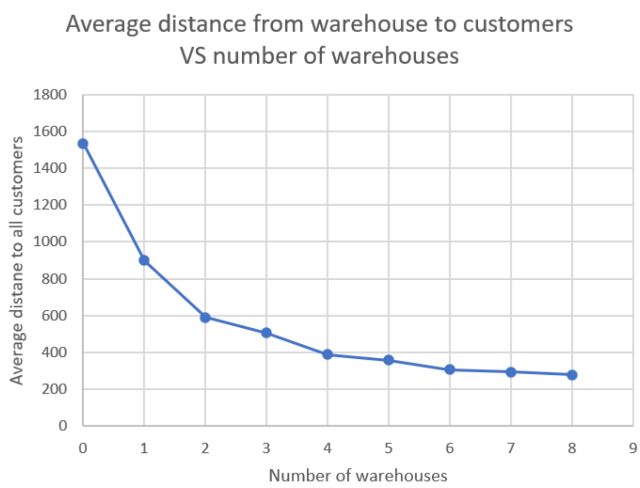

Figure 20: Average distance from warehouse to customer against the number of warehouses

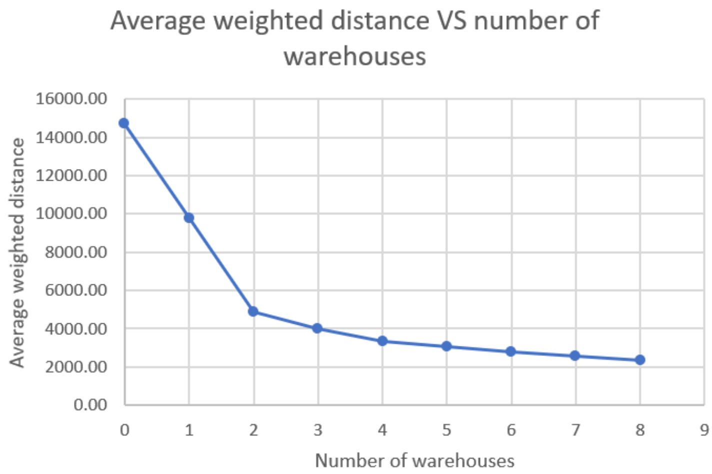

Figure 21: Average weighted distance from warehouse to customer against the number of warehouses

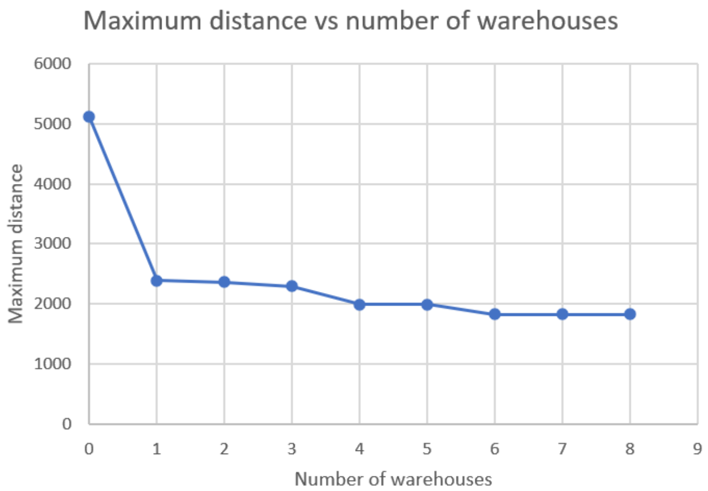

Figure 22: Maximum distance from a customer to a warehouse

Furthermore, utilizing additional warehouses incurs extra renting and handling costs. This would not be a problem if the savings on transportation costs are larger such that building extra warehouses would be more profitable. From Figure 24 it can be concluded that this is the case when utilizing 2 warehouses. Additionally, from Figure 24 it can be concluded that the difference between the savings on transportation costs and the extra renting costs per year are positive if one or two warehouses are located. The renting costs are higher than the savings on outbound transportation costs when three or more warehouses are built. The largest difference between the savings and extra costs, and thus the lowest total costs, can be seen when utilizing two warehouses. The lowest total costs are visualised in Figure 25.

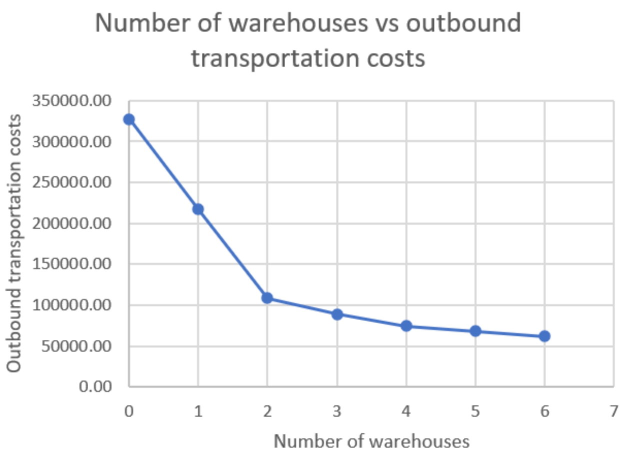

Figure 23: Transportation costs against the number of warehouses located

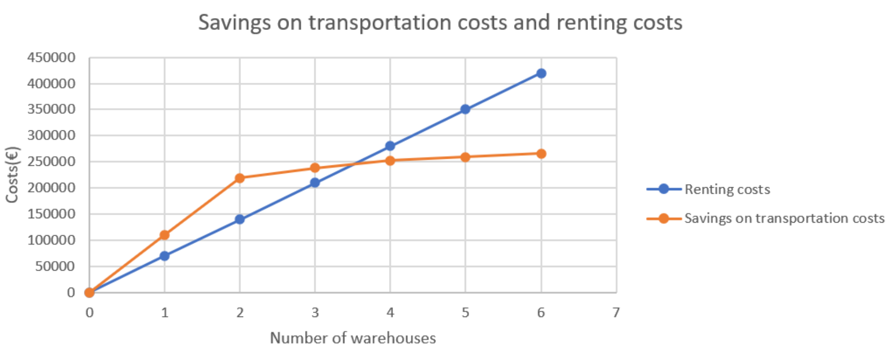

Figure 24: Renting costs and savings on outbound transportation costs per year

Figure 25: Total costs with respect to number of warehouses

Next to the extra costs that come along with locating extra warehouses, the investment costs also rise. In consultation with Company X, it is established that a total stock with a value of 1.5 million is needed in every warehouse. This amount is not considered as costs as the stock placed in the warehouse has a value that will still be sold. Every open warehouse needs a cycle and safety stock. The cycle stock can be divided over all the warehouses as the number of customers assigned to each warehouse decreases as more warehouses are located, but the safety stock is required in every warehouse to deal with demand uncertainty. The safety stock is a large investment that adds to the total investment costs with every extra warehouse that is utilized. The safety stock and corresponding costs are not calculated due to time restrictions. Company X does not want to locate more than two warehouses so a larger cash flow is present in the company to invest in other activities. Furthermore, Company X first wants to experiment with locating warehouses and wants to do this by first locating two warehouses

6.4 Relocating phase

After determining the number of warehouses that should be located, a finer warehouse grid can be used to find a more accurate facility location. In this phase, a distance of 50 kilometres is used for the distance between the grid points. The KPI values are not calculated for the individual experiments for Great Britain and The Middle east because these should be combined in the final situation KPI values which are depicted in Section 6.4.

6.4.1 Relocate warehouse Great Britain

First, a finer grid for Great Britain is used. The grid that is used as an input for the model in this experiment is visualized in Figure 26. In Figure 27, the relocation of the Great Britain facility is depicted. The blue star sign is the new warehouse location and the red star is the old facility location. Using this finer grid also solves the problems of locating a warehouse in the ocean and the assignment of the lower customers in Great Britain to the warehouse at destination X that were described in Section 6.2.2. The warehouse at destination X has been included in this experiment but is not visualised because no customers are assigned to it.

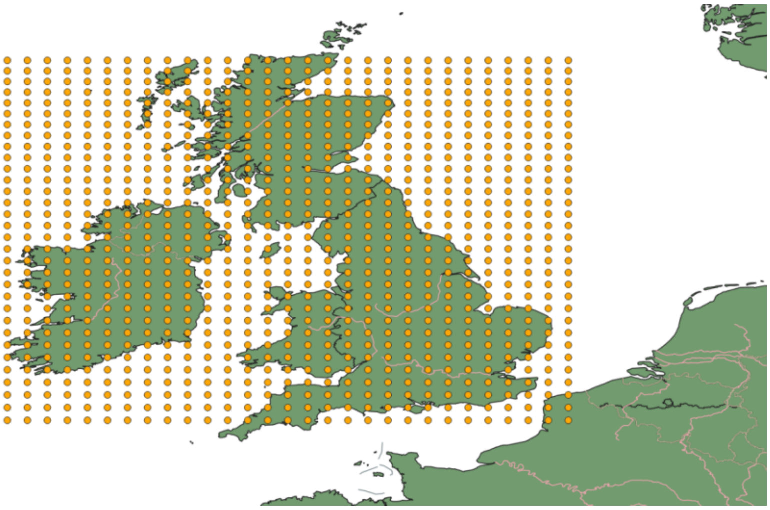

Figure 26: Fine grid for relocating warehouse in Great Britain

Figure 27: Relocating the warehouse in Great Britain

6.4.2 Relocate warehouse in The Middle East

The Middle East warehouse is relocated with the use of the grid visualized in Figure 28. Again, the distance between the grid points is 50 kilometres. The relocated warehouse is visualized with the green star sign in Figure 29. The old warehouse location is depicted with the red star sign. The new warehouse is located on land which solves the problem in the first phase of locating the warehouse in the Persian Gulf which is explained in Section 6.2.1

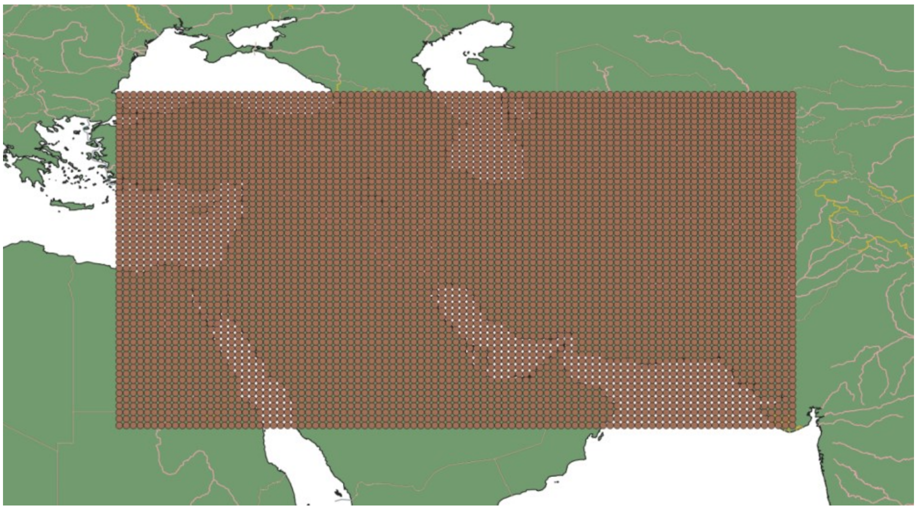

Figure 28: Middle East relocation grid

Figure 29: Relocate the warehouse in The Middle East

6.5 Final warehouse locations

The final situation is visualized in Figure 30. The customers visualized with the green dots have been assigned to the warehouse at destination X because this warehouse is located closest. The warehouse in Great Britain is located near the village of Longridge at coordinates (53.8431154983257, 2.65279301116335). The warehouse in The Middle East is located at coordinates (29.26310887600645, 48.15909389268923). The relocation of the warehouse decreases the weighted average distance from 4879 to 3976 due to using a finer grid. The average distance increased from 573 kilometres to 798 kilometres.

Figure 30: Final warehouse locations

KPI values:

Maximum distance: 2,309 kilometres

Average distance: 798 kilometres

Average weighted distances: 3,976 kilometres

Renting costs: €140,000

outbound transportation costs: €103,171

Total costs: €243,171 per year

6.5.1 Improvements

The main goal of this research is to lower the delivery time from an average of 7 to 8 days to an average of 2 days. To examine the difference in shipping time between the current and new situation, the delivery times for both the current and new situation are calculated with a transit time calculator on searates.com. The average delivery time extracted from the shipping data from Transsmart that is used in the beginning of this thesis is not used because the delivery time in the new situation cannot be extracted from any data and is therefore calculated with an online calculator. Comparing the delivery times of two different sources would represent an incorrect improvement between the old and new situation. In Table 6 it can be seen that the delivery time to almost every country is improved. The customers that did not improve are still assigned to the warehouse at destination X because for these customers, Destination X is located closest.

Country	Average delivery time(days) current situation	Delivery time current situation(calculated by searates.com)	Delivery time new situation calculated by searates.com)
Great Britain	2.9 days	1 day 9 hours	10 hours
Qatar	4.2 days	5 days and 18 hours	9 hours
United Arab Emirates	4.4 days	6 days	14 hours
Israel	5.3 days	3 days 20 hours	21 hours
Saudi Arabia	5.6	5 days and 2 hours	1 day and 22 hours
Morocco	7.8	4 days and 17 hour	4 days and 17 hour
Uzbekistan	8.3	5 days and 16 hour	1 day and 14 hours
Turkey	10.6	3 days and 12 hour	1 day and 2 hours
Kuweit	11.2	5 days	1 hour
Tunisia	15.4	7 days and 15 hours	7 days and 15 hours
Algeria	NODATA	5 days and 7 hours	5 days and 7 hours
Egypt	NODATA	2 days and 10 hours	1 day and 4 hours
Azerbaijan	NODATA	2 days and 8 hours	20 hours
Average		4 days and 12 hours	1 day and 22 hours

Table 6: Average delivery time per country

The delivery time calculated by Searates.com is *"based on various shipping lines and nautical agencies and has been collected for over ten years and is regularly updated"* as mentioned on the website. There is no additional information given about the source of the data and how the delivery times are calculated. To improve the validity of the calculated transit times, other calculators were searched so a comparison between the two calculated values could be made. However, other transit time calculators that are found on the internet do not give any results for the routes from the newly located warehouses to the customers, or a paid subscription is needed to calculate the transit times.

The improvements of the other KPIs are summarized in Table 6. Almost all KPI values decreased after theoretically implementing the two warehouses in The Middle East and Great Britain. The renting costs increased from €0 to €140,000 because two warehouses are utilized.

KPI	**Current situation**	**New situation**	**Change(%)**
Average distance	1523.18 km	798.83 km	-47.56%
Average weighted distance	14750.78	3976.15	-73.04%
Maximum distance	5108,11 km	2309.44 km	-54.79%
Average delivery time	4 days and 12 hours	1 day and 22 hours	-56.69%
Outbound transportation costs	€327249.07	€103171.44	-68.47%
Renting costs	€0	€140000	-
Total costs	€327249.07	€243171,44	-25,69%

Table 7: KPI comparison

Another improvement, that cannot be quantified, is the fact that the time shipments spend at the border patrol is not included in the outbound shipment for the customers in the country where the warehouse is located. These customers thus do not experience extra shipping time due to border patrol delays anymore. The border patrol time is now included in the inbound shipment and the extra shipping time can be accounted for when calculating the reorder point of the inbound shipment. This improvement holds for the customers that are located in Great Britain and Kuwait and not necessarily for the remaining customers. Therefore, future research is needed to research which countries have the best political relations with other countries in order to minimize border patrol time.

6.6 Conclusion

The first phase determined that two warehouses should be implemented. Building more than two warehouses does not incur large improvements in average shipping distance, weighted average shipping distance and maximum distance, but every additional warehouse does incur extra renting costs. Furthermore, the difference in outbound transportation costs and renting costs per year is largest when two warehouses are built. The semi-optimal warehouse locations are located in the ocean next to the island Isle of Man and in The Persian Gulf. The relocation phase determined two optimal warehouse locations with the use of a finer grid. The new optimal location for the warehouse in the Middle East is located at coordinates (29.26, 48.16) and the optimal location in Great Britain has coordinates (53.84, -2.65). With these improved locations, the average distance increased from 573.05 (before the relocation) to 798.83 kilometres (after the relocation). The increase in average distance is attributable to the fact that the objective is to decrease the weighted distance and not the distance. The weighted average distance decreased from 4879.52 kilometres (before relocation) to 3976.15 kilometres (after relocation). Comparing the current situation with the new situation shows us that the average delivery time over all countries decreased from 4 days and 12 hours to 1 day and 22 hours. The average weighted distances decreased from 14,751 to 3,976. The outbound transportation costs decreased from €327,249 per year to €103,171 per year. Locating two warehouses incurs a total renting cost of 140,000 per year. The total costs thus are established to be €243,171. The total costs thus decreased from €327,249 to €243,171.

7. Validation and verification

In this chapter, the validity of the model and data collection methods are discussed so that the results are more trustworthy, and the solution can be implemented in the future. The first discusses the geocoding tool that is used to extract coordinates from the customer addresses. The second section discusses the validity of the distances calculated by the Python code. The second section covers the functioning of the model.

7.1 Geocoding tool

The addresses that are retrieved from the shipments in the Excel sheet have been used to extract the coordinates with the use of an Excel geocoding tool. To validate the coordinates that were extracted by this tool, a sample test with four addresses is executed. Both the address that was filled in in the tool and the coordinates that were extracted by the tool have been filled in in google maps to see if the positions on the map correspond with each other, or if an error has been made by the tool. The four samples have been depicted in Table 11 in Appendix C. It can be seen that three out of the four coordinates have an error below 25 kilometres and that one coordinate has an error of 287. It has been decided that these errors are acceptable. Figure 36 To Figure 43 Show images of the locations based on the address and coordinates on Google Maps to validate the Geopy library used in the Python code.

7.2 Distance calculation

The distances between the potential warehouses (grid points) and the customers of Company X are calculated with the Geopy library inside Python. It is tested whether these distances are correct, by comparing them with the distances calculated by the haversine formula in Excel. The haversine formula is depicted below.

$$\begin{aligned}\text{Distance:} \cos^{-1}((\cos 90 - latidude1)) \\ * \cos(90 - latidude2) \\ + \sin(90 - latidude1) * \sin(90 - latidude2) * \cos(longitude1 - longitude2))\end{aligned}$$

The Excel sheet that is used for this can be seen in Appendix C. In this same appendix Table 10 shows that the distances that are calculated by the Python code(Geopy library) are almost the same as the distances calculated by the haversine formula. Furthermore, Google Maps is used to determine the point-to-point distance between warehouses of a small sample. The distances calculated by google maps are approximately the same as the distances calculated by the model. The validity test with Google maps is only performed six times because this method is very time consuming.

7.3 Warehouse location

The optimal warehouse location that is determined by the model is based on the weighted distances between the potential warehouse locations and the customers. To test whether this mechanism works, the weight (demand) of a small customer with demand 1, is increased to a very high number to see if the warehouse is located closer to the customer with the increased weight. The customer that is highlighted with a red dot in Figure 31 currently has a weight of 1. In this validity experiment, the demand of this customer is increased to 1000000 to see what effect this has on the optimal location calculated by the model. Figure 32 shows that the new optimal location is exactly on the customer with the increased demand. A second test, with a moderate increase to a weight of 600 shipments, is visualized in Figure 33. This test shows that the model locates the new warehouse in between the old and new location. This test is only executed with the use of the Great Britain relocation code because all other experiments use the same code and thus work the same.

Figure 31: Validation of the model code, before weight increase

Figure 32: Validation of the model code, after large weight increase

Figure 33: Validation of the model code, after moderate weight increase

8. Conclusion

This chapter concludes if the research question stated in Section 1.4.2 is answered and what improvements have been made. The improvements are quantified with the use of the KPI values. The goal of this research was to investigate how to improve the delivery time of consumable deliveries by balancing out delivery time performance and total costs.

Warehouse type and configuration

The first step was to research the type of facility that best fits the problem. Several warehouse types were considered from which the product fulfilment centre is chosen. The product fulfilment centre handles activities such as order picking, customer service and inventory management which are all important in shortening the delivery time to customers. The second decision is about whether to use a private or public warehouse. Since private warehouses require a large building or buying investment, as Company X wants to retain a large cash flow to invest in other activities, a public warehouse will be rented. The warehouse will be restocked with the use of bulk shipments from the warehouse at destination X.

Warehouse locations

The optimal warehouse location is determined with the use of a p-median model. The input for this model is a finite set of possible facility location points and the number of warehouses that should be built, represented by the variable P. To determine the number of warehouses that should be built, an experiment phase is designed in which experiments with different P-values are executed. In this phase, a grid with a distance of 500 kilometres between points is used. The KPI values have been calculated across the experiments to examine the improvements that are made by increasing the P-value. After this phase, an intermediate decision about the number of warehouses and the assigned customers is made, based on the KPI values. It is determined that the decrease in average distance, weighted average distance and transportation costs become smaller after locating three or more warehouses. Additionally, the total costs are lowest when locating two warehouses. Therefore, two warehouses are located: one in the ocean next to the island Isle of Man and one in the Persian Gulf between Iran and Saudi Arabia. Both are infeasible warehouse locations because a coarse grid with 500 kilometres in between grid points is used. In the second phase, a more accurate location for the warehouses is found with the use of two separate grids with a distance of 50 kilometres between points. The warehouse in Great Britain is relocated near the city called Longridge at coordinates (53.84, 2.65), while the warehouse in the Persian Gulf is relocated five kilometres from the shore of Kuwait at coordinates (29.26, 48.16).

Improvements

After theoretically implementing the solution, all KPI values have improved. The average weighted distance decreased from 14,750 to 3,976. The outbound transportation costs decreased from €327,249 per year to €103,171 per year. Locating two warehouses incurs a total renting cost of 140,000 per year. The total costs thus are established to be €243,171 in comparison to the €327,249 of the current situation. Distance KPIs are calculated with the library Geopy within Python. The average delivery time is calculated with an online calculator called searates.com. The average delivery time is not extracted from the shipping data because then it would not be possible to compare them to the values of the new situation as those are also calculated with the online calculator. The outbound transportation costs are calculated by multiplying the sum of all weighted distances by the transportation costs of €0.118. To answer the research question *How can the lead time of consumable deliveries to global customers be improved, balancing costs and lead time performance?*: based on the weighted distances, 2 warehouses should be built at the coordinates (53.84, 2.65) and (29.26, 48.16). Doing this achieves a decrease of 56.69% in average delivery time and a decrease of 25.69% in total costs.

Future research is needed to verify the feasibility of the calculated locations. Additionally, locating the warehouses at the proposed locations, completely removes the time orders spend at the border patrol in outbound shipments to customers in Great Britain and Kuwait. So, an additional problem identified in the problem identification chapter, the delay at the border patrol, is also solved partially. This problem is solved only partially because it is not yet known if the border patrol times decrease for other customers in the Middle East. Future research needs to be conducted to find out which country has the best political relations with other countries so that the border patrol time can be minimized.

9. Discussion and recommendations

Before implementing the solution by acquiring warehouses at the advised locations, a discussion is needed to give insights into how the solution should be interpreted. It is also considered whether the solution can be implemented immediately or if some parts of the research need more attention. Additionally, this chapter covers the key findings from this research by discussing the methods that are used.

The first discussion point is the model and the data that is used to calculate the optimal warehouse location. The distances that are used to calculate the weighted distances between the possible warehouse locations and the customers are measured point to point and in a straight line, instead of considering the real route travelled when shipping the consumables. It is possible that some customers are located close to the warehouse, but the route to these customers is poorly accessible. In this situation, the distance would not reflect the actual travelling time of the shipment. However, measuring the actual travel time from every possible warehouse to every customer would be extremely time consuming. Therefore it is decided to not calculate the exact travel time in this research. However, using the travel time instead of the distances would give a more accurate location and can be profitable in future research.

The model does not consider the presence of the important warehouse location factors that are discussed in Section 3.3. The proximity of sea- and airports, for example, is an important aspect as some customers are still located distantly from the warehouse and the consumables are likely to be shipped by plane. Law and regulations in the country of locating the warehouse are also not taken into account. In future research, these aspects should be researched for every warehouse location. When all or some aspects are not present, a new warehouse location that satisfies these prerequisites near the original warehouse location may be considered. Political relations between the country where the optimal warehouse location lies, and the surrounding countries have to be investigated to run the process of border patrol and paperwork without complications.

The capacity of the warehouses is not considered when assigning customers to the warehouses. The capacity of the possible warehouses is not known as locations are points on a map instead of existing warehouses. The capacity of the warehouse should be determined based on the cycle and safety stock and should be a selection criterion when searching for a warehouse in future research.

The inbound transportation costs are not calculated and incorporated into the cost figures because the order frequency and optimal order quantity are not calculated in the research. Including the inbound transportation costs in a future cost calculation will increase the total transportation costs.

The outbound transportation costs are calculated by averaging multiple values in the process. This is done because searching the information needed to calculate the shipping costs for every individual shipment is very time consuming. The average weight of all shipments in the past year is used to find the corresponding row in the shipping costs table of DHL. Then the average costs over all shipping zones is taken to determine a price per shipment. These costs are then divided by the average distance of all shipments from the last year to get an outbound transportation costs per kilometre. Additionally, the transportation costs are calculated by summing all weighted distances and multiplying this by the transportation cost per kilometre. This assumes that the truck is only driving to the warehouse and does not return. Doubling the transportation costs would also not represent an accurate transportation cost because often trucks do not drive back and forth to every customer individually. Instead, a vehicle routing pattern is used to deliver the products in an efficient manner. Therefore, in this thesis, only the route to the customer is taken into account when calculating the transportation costs.

In the calculation of the warehouse renting costs, it is assumed that every additional warehouse costs the same amount of money per year. This is not realistic as every additional warehouse does not need the same amount of cycle inventory because less customers are assigned to every warehouse if an extra warehouse is utilized. However, the total inventory that is needed cannot be divided by the number of customers because every warehouse needs safety inventory on top of the cycle inventory. Due to the absence of information about the cycle and safety inventory the same renting cost increase is used for every additional warehouse. In order to calculate the real renting cost of the warehouses, future research in which the cycle and safety stock are calculated is needed.

The total costs calculation is thus merely a rough estimation and should be revised when information about the cycle inventory, safety inventory, the reorder point, order frequency and optimal order quantity is known. The cost figures in this thesis should not be used to base final decisions on and are mainly meant for illustrative purposes on how the cost figures vary with different numbers of warehouses.

The validity of the comparison made between the current and new delivery time is debatable. Although it is chosen to compare the delivery time from the current and new situation from the same source (Searates.com) and not from the shipment data, it is still not certain whether the calculated times by Searates.com are valid. Searates.com is used because delivery time calculators of transportation companies need memberships or business accounts to function properly.

This research has found optimal locations for various numbers of warehouses with the use of the P-median model. At first, the P-median model only uses the weighted distances and does not take into account the total costs. However, with the use of the experiment design in this research, several scenarios have been analysed with the use of key performance indicators. Having used this process in finding the optimal locations, both the weighted distances and the total costs that are involved with every scenario are covered. Furthermore, the use of a grid for the potential warehouse locations is a highly effective manner to cover many warehouse locations. Normally, P-median models require a lot of research to find possible existing potential warehouse locations. With an area of roughly 50 million kilometres that must be covered in this research, this approach would not be feasible within the ten weeks this research spans.

The added value of this research for Company X is extensive. Company X has been planning to locate a storage location in the concerned regions in the past. In order to realize this, an initial decision based on the distances between customers, the potential warehouse location, and the demand of these customers is needed. Company X can continue the process of locating warehouses by researching the recommendations that are mentioned in this section. Furthermore, Company X can use the produced code and methods to research optimal warehouse locations in the future, in case of a demand change or the need of locating a warehouse in other regions.

Bibliography

Ansari, A. & Modarress, B. (2010). Challenges of outsourcing logistics to third-party providers. *International Journal of Logistics Systems and Management*, *7*(2), 198. https://doi.org/10.1504/ijlsm.2010.034426

Bardi, E. J. & Tracey, M. (1991). Transportation Outsourcing: A Survey of US Practices. *International Journal of Physical Distribution & Logistics Management*, *21*(3), 15–21. https://doi.org/10.1108/09600039110134986

Christofides, N. & Beasley, J. (1982a). A tree search algorithm for the p-median problem. *European Journal of Operational Research*, *10*(2), 196–204. https://doi.org/10.1016/0377-2217(82)90160-6

Christofides, N. & Beasley, J. (1982b). A tree search algorithm for the p-median problem. *European Journal of Operational Research*, *10*(2), 196–204. https://doi.org/10.1016/0377-2217(82)90160-6

Daskin, M. S. (2008). What you should know about location modeling. *Naval Research Logistics*, *55*(4), 283–294. https://doi.org/10.1002/nav.20284

Demirtas, D. (2016). Facility Location under Uncertainty and Spatial Data Analytics in Healthcare. https://www.proquest.com/openview/f54842e628c10a7b4ad1f51041c3d9d4

Dündar, O. O. & Öztürk, r. (2020). The effect of on-time delivery on customer satisfaction and loyalty in channel integration. *Business & Management Studies: An International Journal*, *8*(3), 2675–2693. https://doi.org/10.15295/bmij.v8i3.1520

Erlenkotter, D. (1981a). A comparative study of approaches to dynamic location problems. *European Journal of Operational Research*, *6*(2), 133–143. https://doi.org/10.1016/0377-2217(81)90199-5

Frazelle, E. H. (2016). *World-Class Warehousing and Material Handling, 2E*. McGraw-Hill Education.

Geoffrion, A. M. & Graves, G. W. (1974). Multicommodity Distribution System Design by Benders Decomposition. *Management Science*, *20*(5), 822–844. https://doi.org/10.1287/mnsc.20.5.822

Goldman, A. J. (1971). Optimal Center Location in Simple Networks. *Transportation Science*, *5*(2), 212–221. https://doi.org/10.1287/trsc.5.2.212

Graves, G. W. (1974). Multicommodity Distribution System Design by Benders Decomposition. *Management Science*, *20*(5), 822–844. https://doi.org/10.1287/mnsc.20.5.822

Izdebski, M., Jacyna-Gołda, I., Wasiak, M., Jachimowski, R., Kłodawski, M., Pyza, D. & Żak, J. (2018). The application of the genetic algorithm to multi-criteria warehouses location problems on the logistics network. *Transport*, *33*(3), 741–750. https://doi.org/10.3846/transport.2018.5165

Klose, A. & Drexl, A. (2005). Facility location models for distribution system design. *European Journal of Operational Research*, *162*(1), 4–29. https://doi.org/10.1016/j.ejor.2003.10.031

Logistics Systems: Design and Optimization. (2005). *Logistics Systems: Design and Optimization*. https://doi.org/10.1007/b106452

Mirchandani, P. B., Oudjit, A. & Wong, R. T. (1985). 'Multidimensional' extensions and a nested dual approach for the m-median problem. *European Journal of Operational Research*, *21*(1), 121–137. https://doi.org/10.1016/0377-2217(85)90096-7

Nicolai J. Foss. (1997). Resources, firms, and strategies : a reader in the resource-based perspective. *Research Papers in Economics*.

Rothlauf, F. (2012). Representations for evolutionary algorithms. *Proceedings of the fourteenth international conference on Genetic and evolutionary computation conference companion - GECCO Companion '12*. https://doi.org/10.1145/2330784.2330921

Stevens, J. (2016). *Supply Chain Management: Strategy, Operation & Planning for Logistics Management*. CreateSpace Independent Publishing Platform.

Warszawski, A. (1973). Multi-Dimensional Location Problems. *Operational Research Quarterly (1970-1977)*, *24*(2), 165. https://doi.org/10.2307/3007846

Appendix A: Warehouse functions

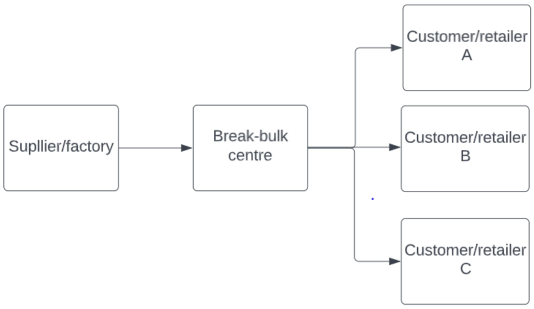

Figure 34: Break-bulk centre

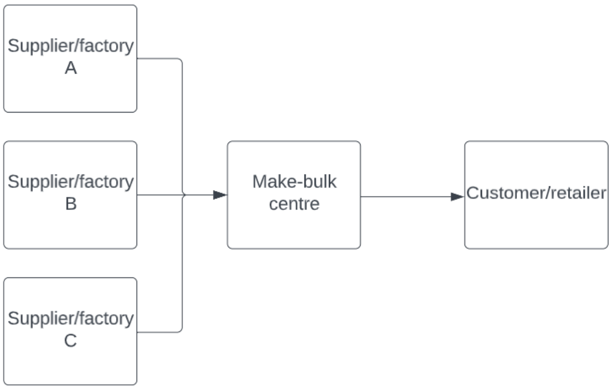

Figure 35: Make-bulk centre

Appendix B: Experiments with grid point distance

Distance grid points first phase(Km)	**Run time**
100	8 minutes and 48 seconds
200	2 minutes and 14 seconds
300	57 seconds
400	31 seconds
500	22 seconds

Table 8: Experiments with grid point distance in the first phase

Distance grid points relocation phases	**Run time**
10 km	Python out-of-memory error
20 km	Python out-of-memory error
30 km	6 minutes and 39 seconds
40 km	6 minutes and 11 seconds
50 km	2 minutes and 3 seconds

Table 9: Experiments with grid point distance in the second phase

Appendix C: Validation and verification

latitude	longitude	Distances haversine	Distances Python code	Google Maps test(small sample)
54.60189	-1.57749	591.2927961	592.91083	
54.64411	-1.20046	570.7711048	572.3048144	
29.35441	47.95638	4233.639845	4238.242605	
51.14578	-0.22918	480.9910229	482.3714075	
54.51202	-6.17638	873.2104602	875.8317161	
35.67607	10.83473	1882.098012	1880.810095	
51.46253	-0.39707	482.3632199	483.7950092	
54.29078	-5.9181	852.3089653	854.8845892	
54.35093	-1.44082	573.0224207	574.6231352	
55.74361	-4.67137	821.5139291	823.7516926	821.40
53.58623	-1.39775	546.9935006	548.6220919	
52.93752	-1.47006	541.7932204	543.4612304	
53.87401	-2.75694	641.0727408	642.9832241	
54.64587	-1.66601	598.4171971	600.0523889	
53.75773	-2.70344	635.0765195	636.9806277	
55.76635	-4.21852	796.5667727	798.7057806	
53.17677	-3.06386	650.0388046	652.0429131	
53.42114	-1.36844	541.6387759	543.2680922	
52.63601	-2.09401	582.5286577	584.3372893	
54.50126	-6.1972	874.302283	876.9285363	
52.46925	-2.07717	581.6655128	583.4726546	581.55
54.35093	-1.44082	573.0224207	574.6231352	
51.79464	-4.07454	724.4700147	726.7047205	
40.74026	30.43669	2221.946638	2225.864408	
54.23197	-1.32876	561.7452595	563.327514	
57.23213	-2.3554	786.7790762	788.5006735	
53.78043	-1.71541	572.0849837	573.7736913	
54.17822	-0.53273	511.0537376	512.4647871	
41.30008	69.29435	4773.165606	4785.70799	
55.02647	-6.68566	917.400693	920.1075619	917.31
39.85952	32.8255	2436.414619	2440.698045	
40.37559	49.8328	3518.196485	3526.489872	
24.48581	54.63641	5074.589362	5078.731462	
41.5059	35.84923	2508.781781	2514.132581	
41.04405	29.26062	2127.072799	2130.778394	
53.78702	-2.9147	649.324712	651.2732911	
34.9306	10.7586	1962.936727	1961.446076	
52.6678	0.94838	377.5142628	378.6682311	

54.05955	-0.25934	489.7129417	491.0702744	
22.67145	39.07231	4304.327808	4303.660978	
53.78008	-1.05181	529.7654287	531.3098067	
54.3148	-7.53824	956.6134898	959.5372551	965.52
53.95671	-0.44004	496.9993323	498.4014454	
54.08948	-0.19916	487.2266396	488.5692699	
53.55662	-2.52682	619.7168212	621.5912707	
38.98909	35.43324	2665.77087	2670.464209	
25.66683	55.80782	5050.065981	5055.028215	
55.77061	-4.21057	796.3086248	798.4457428	
54.17309	-1.35302	561.1383392	562.7288631	
50.73929	-1.95375	609.9683506	611.7048738	
53.60539	-0.64892	499.2608287	500.7258366	
37.08538	37.38972	2936.193989	2940.854116	
29.35441	47.95638	4233.639845	4238.242605	
53.75773	-2.70344	635.0765195	636.9806277	
55.02398	-6.69208	917.7323021	920.4406767	
54.35086	-1.44228	573.1084059	574.7094413	
52.93717	-1.47066	541.830457	543.4986051	
53.57846	-2.42984	613.7948481	615.6474145	
50.73916	-1.95362	609.9648133	611.701301	
54.64445	-1.20191	570.8717187	572.4057286	
40.37559	49.8328	3518.196485	3526.489872	
55.74361	-4.67137	821.5139323	823.7516957	
53.50727	-1.45125	548.7490094	550.3926496	
51.79498	-4.07525	724.5124653	726.7473284	
53.17677	-3.06386	650.0388084	652.0429169	
53.59567	-1.41295	548.189471	549.8209395	
54.08937	-0.20041	487.2979441	488.6408524	
54.09327	-0.18572	486.5615197	487.9010156	
53.60539	-0.64892	499.2608568	500.7258645	
52.46568	-2.07748	581.6986923	583.5059344	
51.23642	-0.57029	500.6332581	502.0929858	
52.46864	-2.07669	581.6350126	583.4420569	
24.45383	54.3774	5060.654221	5064.717949	
54.60543	-1.57544	591.3189916	592.9364043	
31.59485	34.77784	3244.194709	3246.41077	
54.31479	-7.53824	956.6134145	959.5371802	
53.42114	-1.36844	541.6387669	543.2680832	
54.35086	-1.44228	573.1084059	574.7094413	
54.25221	-7.4425	949.5384834	952.4443562	
53.96139	-2.77021	643.993675	645.903004	
53.87401	-2.75694	641.0727707	642.9832541	641.00
54.42292	-7.59484	961.9186576	964.8498473	
55.74255	-4.66983	821.3791224	823.6165983	
25.92687	49.95672	4652.208908	4655.854104	

53.72338	-1.89765	582.384507	584.1154228	
54.35334	-6.4126	885.0939094	887.7734329	
54.26946	-7.42844	948.8819964	951.7840987	
25.86925	45.41182	4376.03666	4378.520408	
54.85736	-6.56742	905.7366089	908.426033	
53.2972	-3.51791	681.2897454	683.3877177	
52.21417	-2.73262	627.7348522	629.6839359	
52.52216	0.086431	435.1313376	436.4731858	
53.44226	-1.33195	539.6694059	541.2899425	
53.78327	-2.89756	648.1408847	650.085917	
37.06721	36.14587	2860.237253	2864.593505	
27.0077	49.66006	4540.604601	4544.652514	
52.57992	0.992654	374.0212999	375.1674483	
53.55603	-0.67685	499.7796698	501.2530457	
54.26946	-7.42844	948.8819964	951.7840987	
54.34103	-6.54998	893.6554342	896.3651431	
53.96133	-2.76946	643.9443254	645.8534937	
53.11723	-0.63083	487.9870023	489.4684367	
53.72338	-1.89765	582.384507	584.1154228	
24.21462	54.73279	5104.073004	5108.11266	
53.50669	-1.45037	548.6797333	550.3232068	
51.52223	0.180274	441.9745332	443.2830582	
54.09345	-0.18585	486.5766972	487.9162119	
53.6844	-1.58241	561.1856936	562.8499459	
55.77061	-4.21057	796.3086248	798.4457428	
31.22688	34.80819	3278.889823	3280.97374	
54.17309	-1.35302	561.1383392	562.7288631	
52.28489	-2.1698	588.939659	590.7678039	
54.64445	-1.20191	570.8717187	572.4057286	
54.51259	-6.17123	872.8959974	875.5161142	
54.85815	-6.56273	905.4636937	908.1520674	
24.69497	46.72413	4559.792941	4562.062192	
36.06852	4.75912	1812.222015	1810.860869	
41.31234	69.27871	4771.301828	4783.842822	
56.61315	-3.0584	779.4430984	781.3098716	
55.92464	-3.41789	759.3581451	761.3186903	
25.20498	55.27106	5054.255665	5058.881382	
51.86162	-2.64523	626.2200509	628.1480289	
25.31214	55.40102	5053.598315	5058.303833	
54.51259	-6.17123	872.8959974	875.5161142	
54.51259	-6.17123	872.8959974	875.5161142	
25.46155	55.50258	5047.537866	5052.334928	
54.5034	-6.19413	874.1525431	876.7780331	
54.64445	-1.20191	570.8717187	572.4057286	
53.21548	-3.11793	653.985428	655.9999508	
51.58755	-0.04372	455.3501414	456.7097603	

53.72387	-1.89701	582.3548151	584.0855699	
55.02398	-6.69208	917.7323021	920.4406767	
57.22378	-2.34538	785.7186188	787.4381036	
54.28784	-5.9199	852.3686704	854.9448168	
54.55494	-1.3131	573.545843	575.1084838	
51.58755	-0.04372	455.3501414	456.7097603	
53.21548	-3.11793	653.985428	655.9999508	
54.23114	-1.33171	561.896072	563.479011	
55.02166	-6.69712	917.9836265	920.6932022	
54.59	-6.91807	921.8231288	924.6008752	
24.95121	51.55506	4837.54292	4841.140406	
54.18893	-2.73456	647.7901011	649.6808127	
33.92773	-6.90788	2307.905212	2307.451962	
25.35754	55.38827	5048.918413	5053.641207	
51.81339	-2.27482	601.8451972	603.6926846	
25.32498	51.50395	4802.026438	4805.782554	
33.70679	-7.39493	2348.545455	2348.118149	
55.88661	-3.97542	788.4788699	790.5607321	
31.59485	34.77784	3244.194813	3246.410873	
52.8233	1.379937	350.2216734	351.2785062	
55.74246	-4.67763	821.8247221	824.0638872	
54.60666	-1.42637	582.4949482	584.079773	
40.21593	28.95563	2173.655494	2177.0993	
33.47535	-7.68092	2382.859242	2382.413882	
39.79232	32.38205	2414.149066	2418.310982	
41.07513	69.02802	4770.481065	4782.937229	
33.78294	-7.16006	2332.00219	2331.552491	
54.78805	-6.58562	905.2020362	907.8986987	
53.87401	-2.75694	641.0727408	642.9832241	
53.78044	-1.71541	572.0855881	573.7742958	
25.77377	55.93823	5049.555559	5054.596539	
54.20234	-7.57495	957.3909479	960.3274436	
24.45383	54.3774	5060.654221	5064.717949	
33.64476	-7.45427	2357.082075	2356.646498	
41.24712	69.30503	4777.426747	4789.963675	
53.4193	-2.14491	592.404722	594.2021007	
52.27314	0.523103	406.1324428	407.382107	
52.23099	-2.73484	627.7343089	629.6838591	
51.40129	0.236909	441.6447842	442.9358448	
54.20234	-7.57495	957.3909479	960.3274436	
53.79319	-2.64164	631.8508635	633.7400026	
26.40363	50.14121	4622.827362	4626.730247	
50.73381	-1.77602	598.4371079	600.1341486	
33.35584	-7.58549	2391.382283	2390.878099	
33.55989	-7.62952	2372.330957	2371.903008	
31.59426	34.77842	3244.280123	3246.496105	

52.24481	-3.37969	671.3853475	673.4733047	
52.96988	-1.81327	564.9840086	566.7250123	564.92
52.97725	-1.1496	520.745855	522.3437245	
41.07513	69.02802	4770.481065	4782.937229	
36.95439	35.6287	2837.410486	2841.61024	
54.58166	-1.24634	570.725607	572.2723632	
52.73656	0.473154	409.9833575	411.2380892	
51.69241	-4.12504	729.721938	731.9660145	
41.55698	35.88259	2507.409178	2512.777762	
30.64559	31.56196	3156.408516	3157.467605	
30.04463	31.23622	3195.894153	3196.63545	
30.2725	31.73974	3200.500222	3201.45544	

Table 10: Validation of distance calculation

Check number	Address	Coordinates	Error (Km)
1	Centurion Way Bus Pk, Alfreton ,DE21 4AY ,Derby ,GB	(52.937516, -1.47005993)	20
2	4 Warehouse Industrieal Area ,11499 ,Riyadh ,SA	(25.86925, 45.41182)	287.72
3	St. Mevo Maiman 7, Mailbox 860 ,8258127 ,Kiryat Gat ,IL	(31.59485, 34.77784)	0.4
4	Hamariyah Free Zone ,1 ,Sharjah ,AE	(25.46155, 55.50258)	2

Table 11: Validation of geocode tool

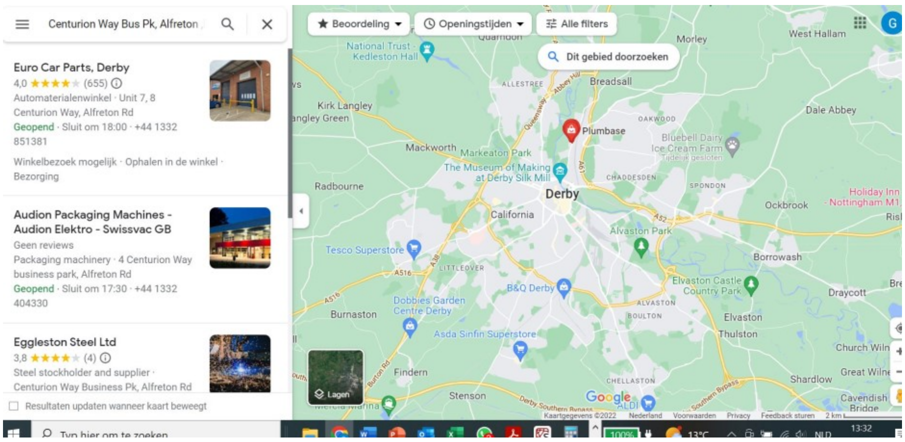

Figure 36: Address check 1

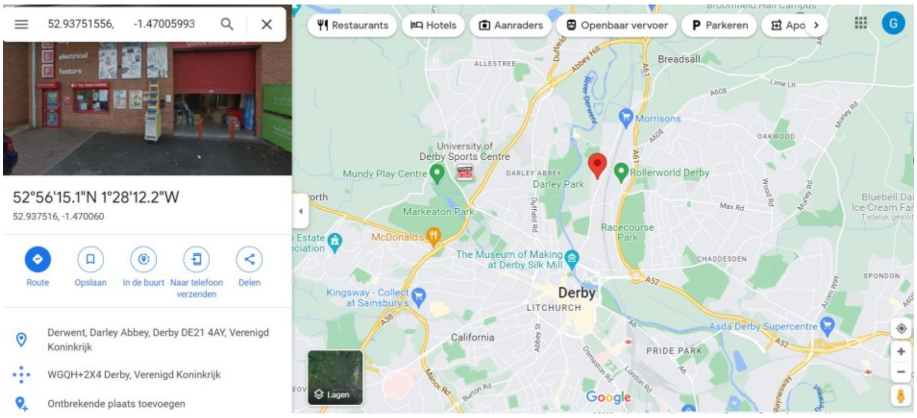

Figure 37: Coordinate 1 check

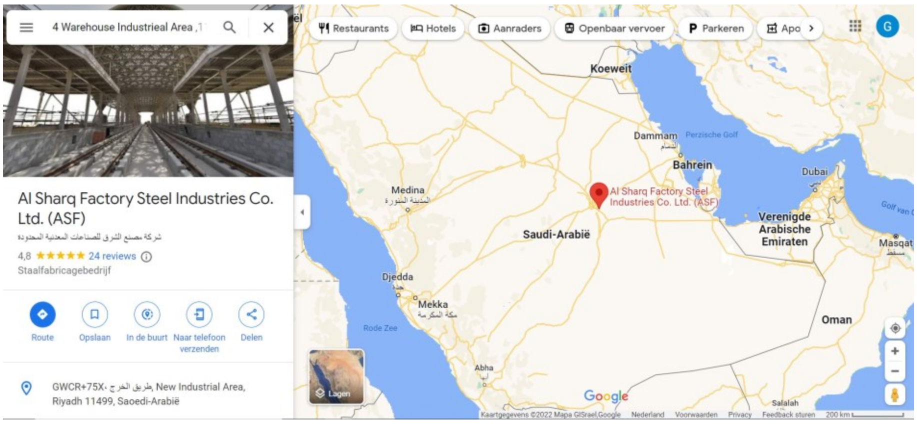

Figure 38: Address 2 check

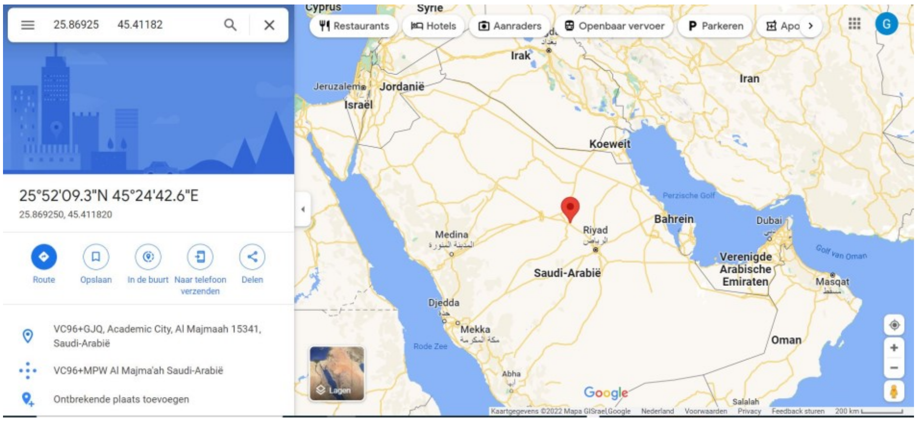

Figure 39: Coordinate 2 check

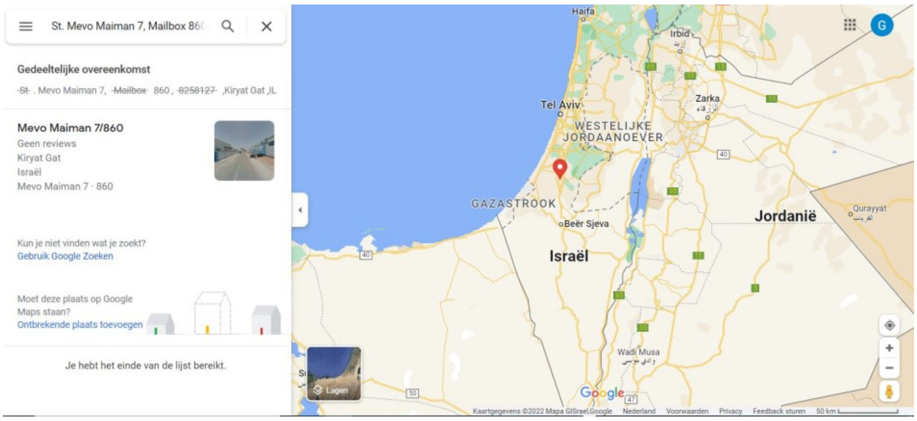

Figure 40: Address check 3

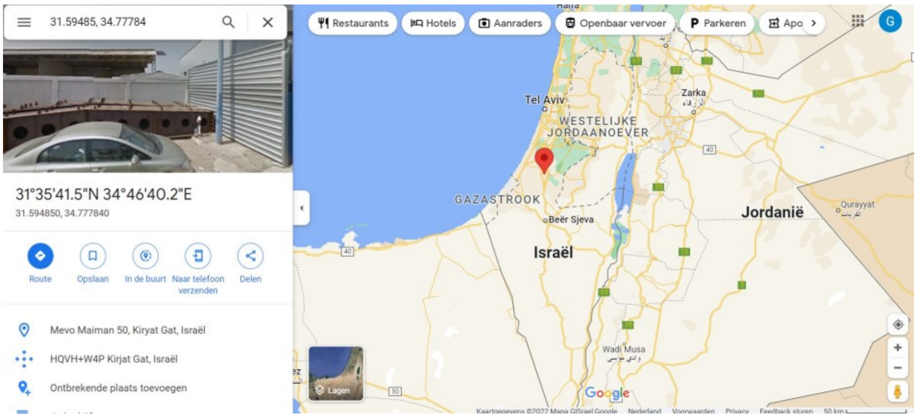

Figure 41: Coordinate check 3

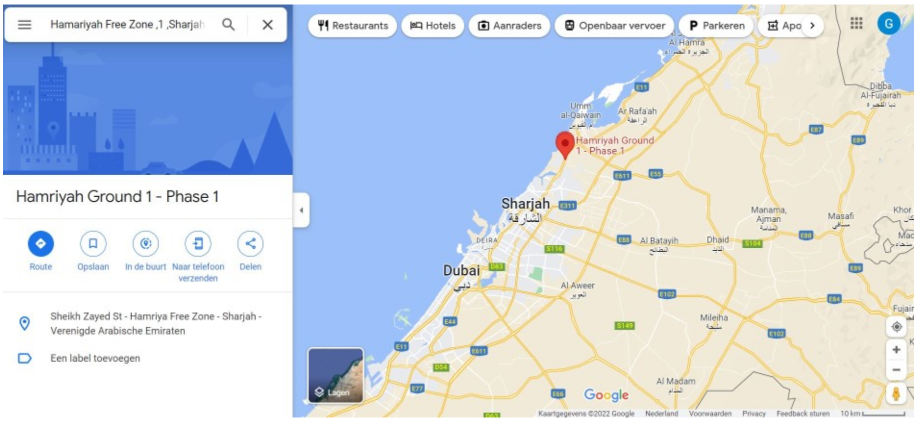

Figure 42: Address check 4

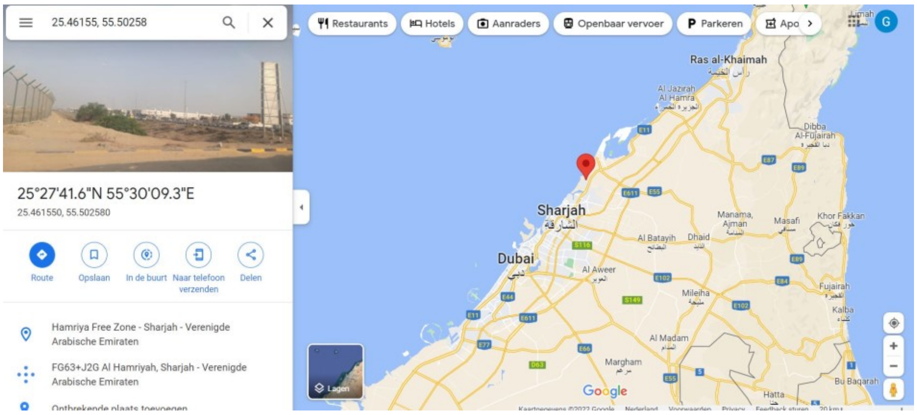

Figure 43: Coordinate check 4