Erasmus University Rotterdam

**MSc in Maritime Economics and Logistics**

*2017/2018*

# Delivery of perishable products via cross docking or direct shipping: A case study for delivery of bananas from port of Rotterdam to distribution centers

by

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## Acknowledgements

Firstly, I would like to express my sincerer gratitude to my supervisor Dr. Bart van Riessen. Because the non-linear programming models are too complicated for me to solve, without the inspirations from Dr. Bart I could not come up with the solutions of non-linear programming models. Besides, without the comments and support from Dr. Bart, my paper would be unrealistic and unclear. The comments and guidance from Dr. Bart greatly helped and encouraged me to complete this thesis. Dr. Bart also recommended me many doctors who gave me idea about how to collect data for my cases study. Highly appreciate the assistance of Dr. Bob Castelein, Dr. Yun Fang and Dr. Heleen Stellingwerf.

Furthermore, I would like to show my appreciation to my family. Without the support and encourage of my family, I could not study in the MEL in the Netherlands and manage to complete this thesis. Thanks so much to my parents who financial and spiritual encourage me during thesis years. Thanks for my boyfriend Mr Wong, who accompanied and helped me when I was struggle with the thesis. Thanks for my uncle Dr. Zhou who helped to check my grammar.

Lastly, I would like to express my thankfulness to professors and faculties from MEL. The study from the modules of Supply chain management, Management science and Business analysis provide me insight in respect of maritime logistics, inventory management and simulation, which are the key elements of this thesis. Without these knowledges, I would not come up with the models and solutions. Also, highly appreciate my classmates in MEL, especially my Chinese classmate such as Garbo and Wuyue. They always supported, encouraged, and helped me when I had difficulties.

## Abstract

Delivery of perishable products is more complicated than delivery of other products, because quality of perishable products is degraded easily, and perishable products have limited shelf life time. Traditionally, products are directly shipped from the terminals to final destinations after being unloaded from the vessels. Cross docking is an innovative distribution strategy that is proposed to improve delivery frequency and to reduce the time of perishable products spent in the supply chain. Therefore, the cross-docking is a new alternative distribution strategy for delivery perishable product with limited shelf life time. In this thesis, we focused on the selection of appropriate delivery strategy for delivery of perishable products. We proposed non-linear programming models to minimize total maritime transport, delivery and inventory costs for two distribution strategies by determining the delivery frequency, delivery quantity and number of vehicles used. Then, we decided the appropriate distribution strategy with minimal total maritime transport, delivery and inventory costs.

We implemented the model by a case study. The case study was inspired by the delivery of bananas from port of Rotterdam to distribution centers. Since the non-linear programming models are too complicated to be solved at this stage, we solved the models though simulations with different delivery frequency. The results show that the appropriate delivery strategy is cross-docking, because total maritime transport, delivery and inventory costs are dramatically reduced by using cross-docking. While using cross-docking, total number of reefer containers used in one week is greatly reduced, resulting lower maritime transport costs. Besides, delivery frequencies are notably improving by cross-docking also, so inventory level in distribution centers are significantly reduced by using cross-docking.

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# Chapter 1 Introduction

Perishable products are referred to products with limited shelf life time, temperature sensitive and high perishability. Environmental conditions such as temperature and humidity will affect the freshness, quality degradation speed and shelf value of perishable directly and significantly. Therefore, protecting the quality and optimizing shelf life of goods are the most importance elements when handling and transporting fresh and perishable products (Chen & Notteboom).

Because of the population growth and the alternation of eating habits, demand for perishable and fresh products continuously grows. Besides, non-traditional seaborne refrigerated products such as pharmaceuticals and flowers start to be shipped by sea freight, because of the technical development of seaborn reefer transportation. Drewry forecasts that demand for seaborne refrigerated products will keep growing and that global perishable reefer seaborn trade will reach 120 million metric tons by 2020 (Drewry, 2017).

On the other hand, the Netherlands is a prime trading hub in Western Europe for perishable products such as fruit and vegetables. Although some perishable food is still domestically produced in the Netherlands, import of perishable food from developing countries grows dramatically not only in volume but also in value. Huge amount of perishable food such as apples, oranges, grapes and banana are imported in the Netherlands and then exported to Western Europe. Germany, Belgium, UK, and France are the top destinations that perishable products are exported to (Cbs.nl, 2018).

As the largest and most import port in the Netherlands, port of Rotterdam has the leading position for handling and storing perishable products not only in the Netherlands but also in Europe. With state-of-the art terminals and advanced cold storage facilities, port of Rotterdam attracts many deep-sea liners and shippers (Port of Rotterdam, 2018). Over one third of food imported from Africa, Asia, and the Americas to Europe flows via port of Rotterdam, as the port of Rotterdam is easily connected to other European Countries though waterway and roadway.

As a result, in this thesis we propose to select the approximate distribution strategy for delivery perishable products from port of Rotterdam to distribution centers of a chain supermarket. We will present two distribution strategies, which are direct shipping and cross-docking. In direct shipping, products are directly shipped to distribution centers after being unloaded from vessels; in cross-docking, products are shipped to a cross-dock center firstly. Sorted and consolidated in cross-dock centers, then, products are shipped to distribution centers after consolidation.

## 1.1 Characteristics of perishable food

Raak, et al., (2017) classify food products into five categories, which are fruits and vegetables, bakery products, chocolate and pralines, and dairy products. Balaji & Arshinder, (2016) mention that fruits and vegetables are the most perishable products as they have very short shelf lives, that one of important criterion of fresh food supply chain is food quality which declines over the time, and that the environmental conditions of transport and storage facilities have significant impact on the degradation speed of food quality.

Compared to the conventional supply chain, food supply chain is more challengeable and complex. The main reason is that the value of food supply chain will be significantly affected by the quality of food, which however is largely depended on the perishable nature and shelf life of the products. Shelf life is defined as the time period within which food remains safe (Raak, et al., 2017). The quality and shelf time of fresh food are affected by many factors such as moisture, PH, temperature, packaging conditions, and storage conditions (Hsiao, et al., 2017). Besides, the quality of fresh food is not constant during the product lifetime, and it will dramatically decrease to zero while reaching the end of its shelf life (Bortolini, et al., 2016).

High fluctuations of fresh food demand and prices, and intensive customer concerns for fresh food safety are also reasons for the challenge of fresh food supply chain (Shukla & Jharkharia, 2013). Uncertainties of customer demand would result in wastage costs for perishable products, as uncertainty would increase the probability of storing unused products which would perish eventually (Malladi & Sowlati, 2018)

Reducing waste in fresh food supply chain will increase economic returns and decrease customer prices for fresh food (Shukla & Jharkharia, 2013).The whole food supply chain consists of five critical activities, which are production, processing, storage, distribution, and disposal (Yu & Nagurney, 2013). Storage and distribution are the major causes for the wastage in food supply chain.

## 1.2 Direct shipping versus cross docking

Direct shipping is a typical distribution strategy. Products will be directly transported from suppliers to final destinations without consolidation. Directly shipping is normally used in the case when the quantities of cargos transported are equal or close to maximal truck capacities (Alinaghian & Amanipour, 2014). So, direct shipping is suitable for shipments with short transport time and low delivery frequency. However, to have low delivery frequency, products should be stored in warehouses for relatively long time. In this senses, direct shipping is appropriate for delivery products with lower holding costs.

To reduce the transport cost while maintaining limited amount of inventory, cross docking is an alternatively suitable distribution strategy to delivery perishable products. Cross docking is an attractive supply chain strategy to consolidate products and enhance the efficiency of logistics operations (Enderer, et al., 2017). Traditionally, shipments are consolidation in warehouses, which allow suppliers to store their products near customers. So, customer service level is improved by the shorter transport lead time. Besides, consolidation of products in the warehouses is significantly reducing transport costs by increasing the utilization of full truck load (FTL). Compared to traditional warehouses, the cross-docking centers do not or only have little amount of storage. Once the products are unloaded from inbound trucks, they will be sorted, repackaged and loaded to outbound trucks as soon as possible. This strategy helps to limit the inventory and reduce the material handling costs inside the distribution center, but still keeps quick responses to customers' needs and supply chain fluctuations. As the characteristics of quality deterioration, perishable products cannot be stored for a long time. Cross docking seems to be an innovative and effective distribution strategy for the distribution of perishable products.

Agustina, et al., (2014) state that cross docking is the best strategy for fresh food distribution, as products could be consolidated before delivery and the distribution is quickly turn-around. Cross docking is able to combine products from different suppliers, resulting lower delivery frequency and lower inventory level (Berman & Wang, 2006). Apart from delivering products in full truck loads (FTLs), in cross docking transport costs can be notably reduced without raising the inventory level and cycle time, while providing a high level of customer service (Apte & Viswanathan, 2000). Aiming at the seamless distribution of products from suppliers to customers, cross-docking is able to enhance distribution lead times and reduce inventory levels (Buijs, et al., 2016).

Furthermore, cross docking also allows shipper to save transport cost for bring back empty containers. Cross-docking enable cargos to be unloaded from containers and transferred to another reefer trucks in cross-docking center which near port side rather than shipping containers to final destination and bring back to the port.

Besides, apart from the traditional transshipment function, cross docking is also able to provide value-added service in the cross-docking center such as quality inspection and labeling (Maknoon & Laporte, 2017). As the demand for the safeguard of food quality has been increasing these years, certification and labeling provide a way to communicate with customer and are able to increase the trust of the customers (Ali, et al., 2017). Besides, the expired dates of products with short remaining shelf-life also could be extended in cross-docking center using advanced packing, storing, or handling (Fauza, et al., 2016).

However, compared with direct shipping, additional set up and handling costs should be paid in the cross-dock center while using cross-docking. Since products should be sorted and consolidated in the cross-dock center, more workforce is employed in the cross-dock to coordinate the information and shipment flows from terminals to distribution centers, resulting higher handling costs in the cross-dock centers. In respect of travel time, travel time is also a determinant for delivery of perishable products, because more time spent in transport results shorter displayed time in the shops. Directly shipping products from terminals to distribution centers without spending time in third parties significantly reduce total travel time and pipeline holding costs.

Since there are advantages and disadvantages of two distribution strategies, the aim of this thesis is to determine the suitable distribution strategy for delivery of perishable products and we evaluate two distribution strategies by a case study inspired by the perishable food distribution from port of Rotterdam to distribution centers of Albert Heijn in the Netherlands.

### 1.3 Problem statement

There are lots of literatures discussing distribution of perishable products or studying distribution strategy of cross docking, but few of them would utilize cross docking as a distribution strategy to delivery perishable products. Besides, existing articles studying distribution strategy of perishable products via cross docking mainly focus on minimizing total costs by vehicle routing design. For example, Agustina, et al., (2014) study food distribution using a cross docking warehouse. They use a vehicle routing and scheduling problem (VRSP) model integrating the delivery time windows to minimize transport and inventory cost for perishable products. However, few of the articles compare the result of cross-docking with direct shipping for delivery of perishable products.

In this thesis, we focus on selecting the suitable distribution strategy for delivery of perishable products from a terminal to distribution centers with minimal total maritime transport, delivery and inventory costs. We assume there is a single terminal that supply a single perishable product. The perishable product has a fixed shelf life, which means the perishable product can only be distributed, stored and displayed in a fixed maximal time in the market. At the end of its shelf life, the value of the product is zero and the product is no longer able to be sold in the market. Besides, the perishable food is only stored in the distribution centers in a fixed proportion of its shelf life. The quality degradation and value loss are gradual during its shelf life.

We propose two distribution strategies for selection. The first one is direct shipping that products are directly shipped from the terminal to distribution center without consolidation. The other is cross-docking that products are shipped to the cross-dock center firstly. There is only one cross-dock center considered in this thesis, and no inventory can be stored in the cross-dock center. After being sorted and consolidated in a cross-dock center, products are directly shipped to each distribution center. Similar with many studies regarding cross-docking, our study regarding delivery strategy of cross-docking consists of two independent shifts (pickup and delivery) in transport process. In this thesis pickup routes start and end at terminals, delivery routes start and end at the cross-dock center, and we only consider direct delivery from the cross-dock center to the distribution centers.

we propose two integer non-linear programing models to evaluate the total maritime transport, delivery and inventory costs for two distribution strategies separately. In the models, there are three critical decisions to be determined:

(1) Determine the weekly delivery frequency for direct shipping and cross-docking respectively.
(2) Determine the number of vehicles used in each replenishment cycle.
(3) Determine the delivery quantity for each shipment.

However, it is too complicated to solve the non-linear programing at this stage. We use simulations to estimate the total maritime transport, delivery and inventory costs in various delivery frequencies and determine the optimal solutions with minimal total costs.

The outline of the paper is as follows: section 2 presents a literature review regarding distribution of fresh food and delivery strategy of cross docking. This section reviews and compares involving problems and methodologies in fresh food delivery and cross-docking. Section 3 presents integer non-linear programing formulations for direct shipping and cross-docking separately. Section 4 presents a case study to select the optimal distribution strategy when demand is constant. Section 5 presents computational experiments when demand is uncertain. Section 6 presents the conclusion, highlighting the contribution and limitation of this research.

## Chapter 2 Literature review

The distribution of perishable products has attached many attentions. As the limit shelf life and its characteristics, additional constraints should be implied for the delivery of perishable food. Besides, as an innovative distribution strategy, cross-docking also appeals many researchers to discuss. Although cross-docking is an attractive distribution strategy for delivery perishable products, handling and transporting perishable products via cross-docking is relatively complicated than other products. In this section, we will review literature related to perishable products and cross docking. we will discuss the common research questions regarding delivery fresh perishable products and regarding cross-docking. Then, we will compare the prevalent objective and decision variables for the delivery perishable food and for optimize cross-docking system, so that we can figure out the suitable model for selecting the approximate distribution strategy for delivery perishable products.

### *2.1 Supply chain of fresh and perishable food*

This section reviews some literatures regarding optimization of food supply chain especially of fresh products. Production rate, degradation speed of the quality of perishable products and consumers' expectation of the quality of the products should be considered when improving the performance of the cold supply chain (Fauza, et al., 2016). Product perishability would affect the inventory level and order frequency as well as transport duration, and additional cost may be incurred as the value losses and disposal costs for perished products (Malladi & Sowlati, 2018). Due to the limited shelf life of perishable products, optimizing inventory and transport are the key parameters in fresh food supply chain.

Inventory should be limited by both space and time (Malladi & Sowlati, 2018)**.** Sellers are not able to store perishable products in order to wait for an attracting market condition, as the quality of perishable products would be deterioration over the time span. As a result, inventory level in regional distribution centers should be relatively low, as perishable products should be delivered to marketplace quickly to prevent degradation and to keep freshness (Rong, et al., 2011). Period to replenish fresh products are constrained by the limited shelf time.

Optimizing delivery frequency is the most common way to save transport cost. However, delivery frequency is a critical parameter while determining the profit, the service level, and the freshness of fresh products. Infrequent deliveries with large lot size is able to reduce transport costs, but decreasing service level or fill rate, losing freshness of perishable products, and shortening remaining shelf lives (Crama, et al., 2018). In contrast, resulting higher transport costs frequent deliveries with small lot size not only able to increase the customer satisfaction and enhance freshness, but also able to reduce food losses and to compensate the expired products by lowering stock volumes (Raak, et al., 2017). When making an operational decision for fresh food inventory system, Shukla & Jharkharia, (2013) mention that demand, deterioration speed, transport lead time, stock out, storage capacity, and retrieval policy are the determinate variables.

Seyedhosseini & Ghoreyshi, (2014) study the production in a production facility and distribution planning from the production facility to distribution centers for food supply chain. The problem involves with inventory management and vehicle routing design. They propose a two-phase algorithm to minimize total production, distribution, and inventory costs while satisfying customers' demand. The optimal lot sizes will be determined by customers' demand in the first phase. Then they determine the vehicle routes in the second phase.

Vehicle routing problem (VRP) is a common model used for distribution problems. The classic vehicle routing problem is designed for optimal delivery routings while minimizing total transport costs. In a VRP models, each customer should be visited and only visited once, and each vehicle with same capacity and characteristics only travels one routing, starting and ending its trip at the depot (Braekers, et al., 2016). Incorporating with real-life, a complex model is proposed for delivery of perishable products that have shelf life time, which is vehicle routing problem with time windows (VRPTW). In VRPTW models, additional constraint is added to ensure that products should be delivered within a time window, which means products should not be delivered earlier than the earliest acceptable time or later than the latest acceptable time (Osvald & Stirn, 2008).

Diabat, et al., (2016) focus on finding the optimal route for each vehicle to deliver perishable products. They present a periodic distribution inventory problem for perishable goods (PDIP), which is close to VRP. The difference of PDIP is that perishable products can only be stored in retailers' warehouses in given shelf life time. So, addition constraint that inventory level of retailers never exceed total demand over shelf life period, should be included in this model.

Federgruen, et al., (1986) present an algorithm to minimize operating costs, which consist of out-of-date costs paid for expired unused products, shortage costs, and transport costs in a scenario that shipments are directly shipped to destinations and in a scenario that deliveries are combined in multi-stop routes. Decision variables in both scenarios are the amount of shipments delivered. An additional decision variable in the scenario two is the assignment of delivery points to a particular route, controlled by the number of available products and vehicles' capacities. The article shows that inventory related costs outweigh travel costs, and that travel costs are greatly reduced while using the combined approach.

To determine the optimal order quantity in cold supply chain, Bozorgi, et al., (2014) introduce the cold items cost and emission model (CICEM). In terms of minimize costs, the authors use first derivative of the total costs to determine the optimum order quantity, which is similar with EOQ model.

Inventory routing problem (IRP) is a prevalent problem to minimize inventory and routing costs in logistics management. The objective of IRP is to minimize the transport and inventory costs within a fixed period while satisfying customers' demand. An IRP consists of three main decision, which are a) when to delivery for each customer, b) how much to deliver to each customer, c) which routes should be used (Crama, et al., 2018).

Crama, et al., (2018) study the stochastic inventory routing problem for a single perishable product (PSIRP), optimizing expected revenue, acquisition costs, and distribution costs to maximize profit while satisfying required service level. The quantities of products delivered, and the number of vehicles used are the main decision variables in this model. They integrate a deliver-up-to-level method and a decomposition method to determine the delivery quantities while satisfying the service level. Then they use vehicle routing problem (VRP) to optimize the routing costs.

Hu, et al., (2018) propose a mix-integer program to solve a two-echelon distribution problem, which combines an IRP problem with a freight consolidation problem for perishable goods with a fixed shelf life. The objective of the model is to minimize total costs including short-haul transport costs for delivery of products from local growers to a consolidation center, long-haul transport costs for delivery products from the consolidation center to final destinations using fixed FTL rates per truck, fixed LTL per units, or linear carries rates per pound, and inventory costs. The authors determine the short-haul pick-up quantities and central inventory levels by solving IRP subproblem.

Coelho & Laporte, (2014) study the combination of inventory management with distribution for perishable products. They propose the perishable inventory-routing problem (PIRP) to maximize revenue and minimize inventory and transport costs. They identify holding costs and selling prices of a perishable product with different aged of the product with the assumption that quality or perceived value of the product deteriorates gradually over its shelf life.

Furthermore, the quality deterioration of perishable products is affected not only by its shelf life time but also by environmental conditions during storage and transport. Rong, et al., (2011) proposed a mixed-integer linear programming, which can be utilized for logistics distribution planning while controlling costs and quality. The total costs including production, cooling, transport, storage and waste disposal costs, are decided not only by production and supply chain management but also by quality and temperature control.

Rong, et al., (2011) and Fauza, et al., (2016) use the following equation to illustrate that quality changed over a period is determined by the product characteristics and storage conditions.

$$\frac{\mathrm{dq}}{\mathrm{dt}} = kq^n$$

Where q and t represent the quality of a product and the time respectively. K is the deterioration rate, and n is the power factor determined by the characteristic of a product.

Using the equation, Rong, et al., (2011) calculate the expected quality of products during a period in particular environment. However, Fauza, et al., (2016) assume that n equals to zero and that k is a constant rate, so the quality deterioration over a period is fixed. Coelho & Laporte, 2014 also assume that quality decays in a fixed rate. Federgruen, et al., (1986), Hu, et al., (2018), Crama, et al., (2018), and Diabat, et al., (2016) also assume the life time of a product is a constant period.

Table 2.1 summarizes the problems discussed regarding delivery of perishable products. Most of the articles use direct shipping as their distribution strategy, except

Hu, et al., (2018) propose a two-echelon distribution problem to consolidate products firstly. These articles mostly focus on inventory management and vehicle routing for perishable products. The inventory level, vehicle assignment and delivery quantity are the key decision variables needed to be determined. Besides, quality control is also an import criterium for delivery perishable products, and temperature used is also a decision variable determined in some articles.

*Table 2.1 Summary of main research problems regarding in distribution and inventory of perishable products*

| Research problems | Inventory management | Vehicle routing design | Freight consolidation | Quality control | Order quantity |
|---|---|---|---|---|---|
| (Seyedhosseini & Ghoreyshi, 2014) | ✓ | ✓ | × | × | × |
| (Crama, et al., 2018) | ✓ | ✓ | × | × | × |
| (Diabat, et al., 2016) | ✓ | ✓ | × | × | × |
| (Federgruen, et al., 1986) | ✓ | ✓ | × | × | × |
| (Bozorgi, et al., 2014) | × | × | × | × | ✓ |
| (Hu, et al., 2018) | ✓ | ✓ | ✓ | × | × |
| (Coelho & Laporte, 2014) | ✓ | ✓ | × | × | × |
| (Rong, et al., 2011) | ✓ | ✓ | × | ✓ | × |

Table 2.2 summarizes the objective variables in models in respect of delivery of perishable products. It shows that articles discussing about delivery of perishable products mainly focus on minimization of transport and inventory costs. Besides, if the storage conditions are not sufficient enough to keep the freshness of perishable products, the quality and the value of perishable products will degrade dramatically. Therefore, to maintain sufficient temperature while minimizing the cooling cost is also a critical objective in distribution and storage of perishable products. If the products are not stored in good conditions or out of their shelf life, the value of perishable products will drop to zero. Therefore, disposal cost for handling the waste is also another dominant objective needed to be considered.

*Table 2.2 Summary of main elements in objective function regarding distribution and inventory perishable products.*

| Research problems | Min production cost | Min cooling costs | Min inventory costs | Min transport cost | Min disposal cost | Max revenue |
|---|---|---|---|---|---|---|
| (Seyedhosseini & Ghoreyshi, 2014) | ✓ | × | ✓ | ✓ | × | × |
| (Crama, et al., 2018) | × | × | × | ✓ | × | ✓ |
| (Diabat, et al., 2016) | × | × | × | × | × | × |
| (Federgruen, et al., 1986) | × | × | ✓ | ✓ | ✓ | × |
| (Bozorgi, et al., 2014) | × | × | ✓ | ✓ | × | × |
| (Hu, et al., 2018) | × | × | ✓ | ✓ | × | × |
| (Coelho & Laporte, 2014) | × | × | ✓ | ✓ | × | ✓ |
| (Rong, et al., 2011) | ✓ | ✓ | ✓ | ✓ | ✓ | × |

## *2.2 Cross docking*

As an innovative distribution strategy, cross-docking has appealed numerous researchers to discuss and optimize the system in recent years.

Serrano, et al., (2016) mention that studies related to cross-docking are mainly focused on three aspects, which are geographic location and cross-docking center layout, network design including cargo flows, distribution planning, and vehicle routing, as well as operational decisions.

Van Belle, et al., (2012) also study the literatures among cross-docking and indicate that four decisions should be made while planning a cross-docking system. Firstly, strategy decision should be made to locate a cross-dock facility. Next, a tactical decision should be made to minimize cost by optimizing the flow of products through the network. The operational decision then should be made to dealing with vehicle routing for picking up and delivering products before and after consolidation. Lastly, internal resource also should be scheduled for unloading, sorting, packaging and loading products.

Since optimizations of vehicle schedules and shop-floor operation schedules are critical activities when improving the performance of a cross-docking system, Serrano, et al., (2016) present a mix-integer linear programming model to minimize internal operation cost and outbound transport cost by making decisions the quantities of products moving within different zones of the cross-dock center such as arrival zone, repack zone, storage zone and departure zone.

Maknoon, et al., (2016) also mention that the workload for handling transshipment in cross-docking center has a direct influence on the operation cost of cross-docking, which accounts for a high percentage of total transportation costs. As a result, the authors present a mixed-integer linear programming model to minimize the amount of double handling and to optimize transshipment workload. Furthermore, the authors also indicate that the transshipment workload can be significantly improved while developing a vehicle scheduling model which are able to deal with uncertain and incomplete information.

Ladier & Gülgün , (2016) analyze gaps between the literatures and the observed industry practices. When optimizing cross-docking in theory, the authors advise that the limited storage and resource capacity should be included as constraints, that the objective to minimize the makespan and the distance traveled is worthless, and that the number of working hours of workload should also be considered as an objective function.

Berman & Wang, (2006) focus on the selection of a suitable distribution strategy for similar products from multiple suppliers to multiple destination though a nonlinear integer program. In the model, the frequency of delivery is the function of routes decision, demands, and vehicle capacity. Then they minimize the sum of transport cost, pipeline inventory cost and plan inventory cost by the decision variables of delivery frequency and transport time. The results show that cross docking is the appropriate strategy when inventory weight is high, as cross docking provides a higher delivery frequency, and that direct shipping is more suitable for the situation where demand is high. Apte & Viswanathan, (2000) also indicate that cross docking is appropriate for products with low unit stock-out costs, with balance demand and supply as well as with relatively constant and stable demand rates.

Besides, Nikolopoulou, et al., (2017) also via Pick-up-and-Delivery Problem (PDP) and Vehicles Routing Problem with Cross Docking (VRPCD) models to evaluate the application of distribution strategy between direct-shipping and cross-docking as well as to identify main factors, that affect total routing costs saving when comparing distribution strategies. The aims for both models are minimizing the total travel costs while satisfying a set of transport requests while deciding the vehicles loaded. The distribution strategy of cross-docking is preferred in the situations when original-destination pairs are in remote position, when suppliers and customers are in many-to-many relation, and when distribution center for transshipments locates in a central position.

Table 2.3 summarizes the literatures discussing about selection of distribution strategies between direct shipping and cross-docking. It shows that cross-docking is suitable for the situation when the inventory costs for products are relatively high or the products is not suitable for being stored for a long time. Besides, cross-docking also suitable for delivery products with not sufficient demand to use full truck load and with long travel distance.

*Table 2.3 Summary of the determinants between direct shipping and cross docking*

| Distribution strategy | Direct shipping | Cross docking |
|---|---|---|
| Inventory weight (Berman & Wang, 2006) | low | high |
| Demand weight (Berman & Wang, 2006) | High | low |
| Balance of demand and supply (Apte & Viswanathan, 2000) | Unbalance | Balance |
| Demand rate (Apte & Viswanathan, 2000) | Unstable | Stable |
| Original-destination pairs (Nikolopoulou, et al., 2017) | long | short |
| Original-destination relation (Nikolopoulou, et al., 2017) | Single | many-to-many |
| Stock out cost (Apte & Viswanathan, 2000) | High | Low |

The essential processes of cross-docking are sort and consolidation products before being loaded to outbound trucks. If the inbound trucks and outbound trucks do not arrive at the cross-dock center simultaneously, the sort and consolidation processes will be delayed, and the staying time of vehicles and the inventory level will increase as result. Therefore, many studies consider the distribution strategy of cross-docking as a problem combining with consolidation decision.

Wen, et al., (2009) optimize the distribution network to transport products via one cross dock, and they consider the problem including vehicle route design and consolidation decision. They present a mixed integer linear programming formulation to determine which vehicles should be used in which routes in order to minimize the total travel time. In the model, they define the duration of unloading is the fixed preparation time plus unloading time per orders.

Maknoon & Laporte, (2017) also study the vehicle scheduling problem and consider the problem involving route design and consolidation. However, in this model, delivery requests pass and are consolidated in multiple cross-docks. The objective of this model is to minimize total travel distance by assigning vehicles among nodes. They study the difference between vehicle routing problem with cross docking and the classical vehicle routing problem. Vehicle routing problem with cross docking allows load exchanges among trucks at the cross-docking centers.

Liao, et al., (2010) consider pick up products from a set of suppliers and delivery products via one cross-dock, and consider the problem integrates with vehicle routing and consolidation. They propose a tabu search (TS) algorithm to minimize the total operational and transport costs by determining the number of vehicles used and the assignment of vehicles.

Furthermore, Agustina, et al., (2014) study the vehicle scheduling and routing for food supply chains in a cross-docking center. They present a customer zones and hard time windows (VRSP-CZHTW) model to determine the inbound and outbound vehicles schedules and delivery routes. The model not only combines vehicle scheduling and vehicle routing problems but also with product consolidation, because the products are sorted and consolidated in the cross-dock center before being loaded onto the outbound vehicle. Besides, the objective of this model is to minimize total cost including transport cost and inventory holding cost, and penalty costs of early and late deliveries. Perishable food products should be delivered within the delivery window specified by customers order.

Enderer, et al., (2017) propose an integrated optimization problem to minimize the total material handling cost inside the cross-dock center and transport cost of outbound trucks from the cross-dock center to customers. They consider material handling and vehicle routing decisions synchronously though two models, namely the Cross-Dock Door Assignment Problems (CDAP) and the Vehicle Routing Problems with Cross-Docking (VRPCD).

*Table 2.4 Summary of main research problems regarding cross docking*

| problem involves | Vehicle routing problem | Vehicle schedule/ Door assignment | Consolidation | Inventory |
|---|---|---|---|---|
| (Wen, et al., 2009) | ✓ | × | ✓ | × |
| (Maknoon & Laporte, 2017) | ✓ | × | ✓ | × |
| (Liao, et al., 2010) | ✓ | × | ✓ | × |
| (Agustina, et al., 2014) | ✓ | ✓ | ✓ | × |
| (Berman & Wang, 2006) | ✓ | × | × | ✓ |
| (Enderer, et al., 2017) | ✓ | ✓ | × | × |

Table 2.4 summarizes the problems discussed regarding cross-docking. Most of the articles consider vehicle routing problem as the main problem in network design for cross-docking. Therefore, which vehicles should be assigned to which routes is the main decision variable in cross-docking models. Besides, the number of vehicles used, delivery frequency, vehicle schedule (sequence of trucks), release and departure time, and doors assignment are also common decision variables to be determined. Table 2.5 summarizes the objective variables in cross-docking models.

*Table 2.5 Summary of main elements in objective function regarding cross docking*

| Main objective | Minimized travel time | Minimized travel distance | Minimized transport cost | Minimized penalty cost | Minimized Inventory cost | Minimized handling cost |
|---|---|---|---|---|---|---|
| (Wen, et al., 2009) | ✓ | × | × | × | × | × |
| (Maknoon & Laporte, 2017) | × | ✓ | × | × | × | × |
| (Liao, et al., 2010) | × | × | ✓ | × | × | ✓ |
| (Agustina, et al., 2014) | × | × | ✓ | ✓ | ✓ | × |
| (Berman & Wang, 2006) | × | × | ✓ | × | ✓ | × |
| (Enderer, et al., 2017) | × | × | ✓ | × | × | ✓ |

Besides, some constraints are specially implied in cross-docking. For example, Agustina, et al., (2014) subject that departure time of order i should be the same as departure time of outbound vehicle carrying it. That means, the departure time of products carried in the same outbound vehicle should be the same. Service time is also a critical parameter in cross-docking should be decided first. Wen, et al., (2009) define service time in cross-dock center is the fixed preparation time plus loading/unloading time per units. Maknoon & Laporte, (2017) approximate the service time as 10 second per order.

In this section we reviewed the articles regarding delivery of perishable products and distribution strategy of cross-docking. Few articles compare the efficiency of the direct shipping and the cross-docking when delivery of perishable products. Besides, these articles mainly focus on last-mile delivery without consider the efficient of maritime transport. Our study also took into account the maritime transport costs, because maritime transport costs capture huge percentage of total costs of supply chain. Because inventory costs also account for import proportion in fresh food supply chain, we also considered inventory costs in our objective function. Therefore, we combined the common problems involving in delivery of perishable food and cross-docking into our models. In our model, we aim to minimize total maritime transport, delivery and inventory costs. In next section, we will present our models for delivery of perishable food in the direct shipping and the cross-docking respectively.

## Chapter 3 Methodology

In this thesis, we will propose two types of delivery strategies for delivery perishable products with a fixed shelf life time and constant demand over a certain period. Figure 3.1 illustrates the first distribution strategy that all perishable products will be delivered to region distribution centers directly after being unloaded from vessels in the terminals. Reefer container trucks are utilized in this strategy. The vehicles start and end at the terminals.

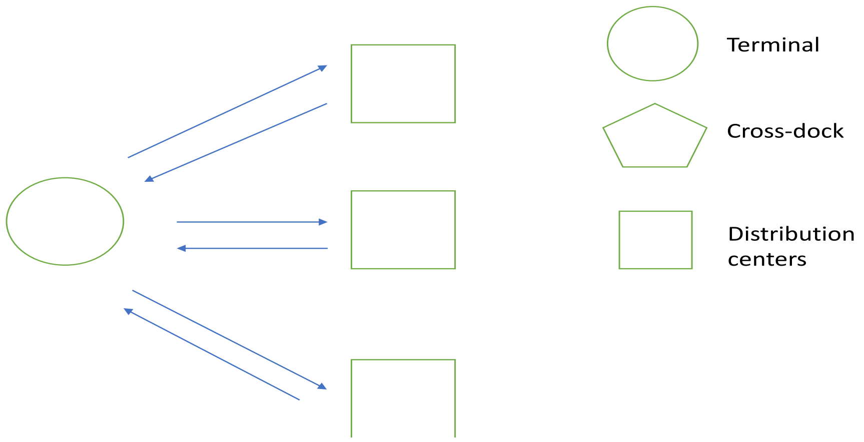


*Figure 3.1 Distribution strategy of direct shipping*
Source: Own elaboration

Figure 3.2 shows the cross-docking strategy. Products will be consolidated in a cross-docking center located near the port firstly, and then will be directly delivered to each region distribution center after being loaded on the outbound trucks. Reefer container trucks that start and end at terminals are used in short-haul pickup routes, and small refrigerator trucks that start and end at the cross-dock center are used at long-haul delivery routes.

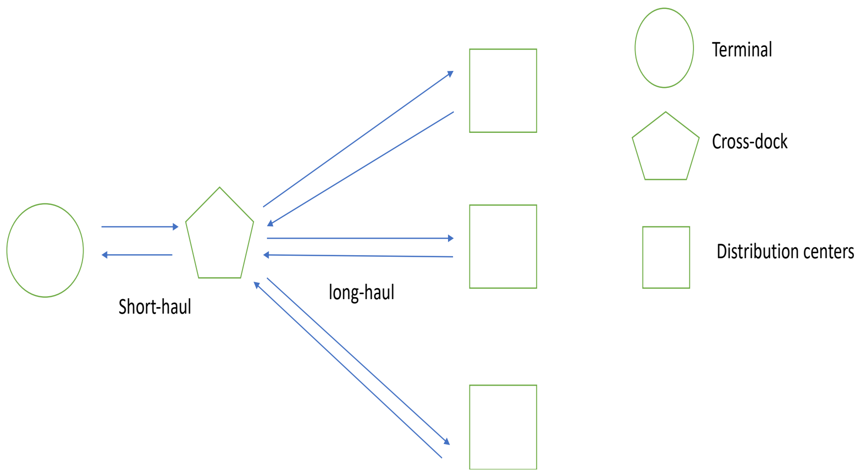


*Figure 3.2 Distribution strategy of cross-docking*
Source: Own elaboration

In our model, we decide to determine the delivery frequency, the number of vehicles used, and the delivery quantity based on weekly demand. The weekly planning horizon is divided into discrete time intervals for each replenishment cycles based on delivery frequencies. Every distribution center makes an order at the end of each replenishment cycle. The delivery quantity and the number of vehicles used in each period are decided by the length intershipment time of the replenishment cycle and the delivery frequency. A replenishment cycle is the interval between two consecutive replenishment deliveries (Chopra & Meindl, 2013).

In the following section, we will propose integer nonlinear programing formulations for direct shipping and cross-docking separately. The programing is nonlinear because the key decision variables in the models are the weekly delivery frequency, the number of vehicles used in each replenishment cycle and the volume of each shipment. However, these decision variables are not independent with each other. The delivery quantities and the number of vehicles used are changed by the deliver frequencies. The model for direct shipping combines vehicle scheduling with inventory management problem for perishable products. The concept of frequency is motivated by (Bertazzi, et al., 2000), as a regular frequency-based process is able to simplify the organization of the terminal and distribution centers. Besides, we use delivery quantity as a decision variable, since delivery quantity significantly affect the inventory costs by deciding the inventory levels. The model for cross-docking additionally integrates product consolidation into the model for direct shipping. The aims of two models are to minimize the sum of transport costs and inventory costs while satisfying all demands from distribution centers.

Furthermore, if delivery frequencies improve, products are more likely to be shipped in less-than-truck-load (LTL) and the number of reefer containers used would be increased. Maritime transport costs would increase as a result. Therefore, to consider the whole distribution network, transport costs include maritime transport cost and inland delivery cost in our models.

In this model, we assume that:

- The demand for each region distribution centers is known and constant, and it is gradually consumed.
- Quality and perceived value gradually deteriorate over its self-life time.
- The products loss their values gradually over their shelf lives, and the value loss shows in terms of holding costs.
- Transport time is zero
- Reefer container trucks will return to the terminals after each delivery; smaller refrigerated trucks will return to the cross-dock centers after each delivery.

Additional assumption for the model of cross-docking:

- There is no inventory in the cross-dock center, so delivery frequency of inbound trucks equals delivery frequency of outbound trucks.
- Material handling costs are considered as a part of set up costs for small refrigerated trucks.

Indices:
I: set of terminals
J: set of distribution centers
O: set of cross-dock centers
i: supplier nodes index
o: cross docking nodes index
j: distribution center nodes index

variables:
$f_{ij}$: replenishment frequency from the terminal i to the distribution center j, $i \epsilon I$, $i \epsilon J$.
$X_{ij}$: the quantity of shipment shipped from the terminal i to the distribution center j in each replenishment cycle. $i \epsilon I$, $j \epsilon J$.
$X_{io}$: the quantity of shipment shipped from the terminal i to the cross-docking center o in each replenishment cycle, $i \epsilon I$, $o \epsilon O$.
$X_{io}$: the quantity of shipment shipped from the cross-docking center o to the distribution center j in each replenishment cycle, $o \epsilon O$, $j \epsilon J$.
$y_{ij}$ : the number of vehicles used from the terminal i to the distribution center j in each replenishment cycle. $i \epsilon I$, $j \epsilon J$.
$y_{io}$ : the number of vehicles used from the terminal i to the cross dock centers o in each replenishment cycle. $i \epsilon I$, $j \epsilon J$.
$y_{oj}$ : the number of vehicles used from the cross dock center o to the distribution center j in each replenishment cycle. $i \epsilon I$, $j \epsilon J$.

Parameters:
$S_i$: quantity of supply in the terminal i
$D_j$: quantity of demand in the distribution center j
B: capacity of reefer container trucks
$\mathrm{B}'$: capacity of smaller refrigerated trucks
M: maritime cost for a reefer container
F: set up cost for a reefer container truck
$\mathrm{F}'$: set up cost for a small refrigerated truck
$C_{ij}$: variable cost for each shipment from the terminal i to the distribution center j.
$C'_{ij}$: variable cost for each shipment from the cross-dock center o to the distribution center j.
$h_j$: holding cost for the distribution center j, $j \epsilon J$.
$T$: the maximal time of a product allowed to stay in distribution centers

### *3.1 Formulation of direct shipping*

Equation (3-1) shows the objective function for direct shipping. The total cost consists of three parts, which are maritime transport costs, inland delivery costs and inventory costs. The inland delivery costs are the fixed handling costs for trucks and the variable costs including fuel consumption and driver wage. The inventory costs equal to average inventory of distribution centers time the holding costs. The average inventory level is half of the delivery quantity.

Objective function:

$$\min \sum_{i\epsilon I}\sum_{j\epsilon J} M * f_{ij} * y_{ij} + \sum_{i\epsilon I}\sum_{j\epsilon J} F * f_{ij} * y_{ij} + \sum_{i\epsilon I}\sum_{j\epsilon J} C_{ij} * f_{ij} * y_{ij} + \sum_{j\epsilon J} h_j \frac{1}{2} X_{ij} * \frac{1}{f_{ij}} \tag{3-1}$$

subject to:

$$\sum_{i} X_{ij} * f_{ij} * y_{ij} \leq S_i \tag{3-2}$$

$$\sum_{j} X_{ij} * f_{ij} * y_{ij} = D_j \tag{3-3}$$

$$1 < \frac{1}{f_{ij}} * T < T \tag{3-4}$$

$$0 \leq X_{ij} \leq \mathrm{B} * y_{ij} \tag{3-5}$$

Constraints (3-2) mean that the total quantities of shipments shipped from terminal i in certain period dose not excess the total quantities supplied by terminal i in that period. Constraints (3-3) ensure that total quantities of shipments shipped to distribution center j in certain period equal to the demand of distribution center j in that period. Constraints (3-4) represent the replenishment cycle of the products. Since delivery quantities do not excess once per day, the intershipment time of a replenishment cycle should be longer than one day. Besides, the intershipment time of a replenishment cycle do not excess the maximal time of the products allowed to stay in distribution centers. $\frac{1}{f_{ij}} * T$ are the length of the intershipment time of a replenishment cycle. For example, if the maximal time of the products allowed to stay in distribution centers is a week, and the delivery frequency is 2 times a week, then the length of the intershipment time of the replenishment cycle $\frac{1}{f_{ij}} * T = \frac{1}{2} * 7 = 3.5\ days$. Constraints (3-5) indicate that the number of trucks must sufficient to load products from terminal i to distribution center j in each replenishment cycle.

### *3.2 Formulation of cross docking*

Equation (3-6) shows the objective function for cross docking. The total cost consists of three parts, which are maritime transport costs, inland delivery costs and inventory costs. Besides, inland delivery costs include inbound distribution costs and outbound delivery costs. The inbound distribution costs are the fixed handling and variables transport costs for reefer container trucks shipping products from terminals in port of Rotterdam to cross-docking centers. The outbound transport costs consist of fixed set up costs in cross-dock centers and the variables transport costs for trucks routing.

The inventory costs are the average inventory costs for distribution centers. The average inventory level is half of the delivery quantity.

Objective function:

$$\min \sum_{i \epsilon I} \sum_{j \epsilon J} M * f_{io} * y_{io} + \sum_{i} F * f_{io} * y_{io} + \sum C_{io} * f_{io} * y_{io}$$
$$+ \sum_{i} F' * f_{oj} * y_{oj} + \sum C'_{oj} * f_{oj} * y_{oj} + \sum_{j} h_j \frac{1}{2} X_{oj} * \frac{1}{f_{ij}}$$

(3-6)

subject to:

$$\sum_{o} X_{io} * f_{io} * y_{io} - \sum_{o} X_{oj} * f_{oj} * y_{io} = 0$$

(3-7)

$$\sum_{i} X_{io} * f_{io} * y_{io} \leq S_i$$

(3-8)

$$\sum_{j} X_{oj} * f_{oj} * y_{oj} = D_j$$

(3-9)

$$1 < \frac{1}{f_{ij}} * T < T$$

(3-10)

$$0 \leq X_{io} \leq \mathrm{B} * y_{oj}$$

(3-11)

$$0 \leq X_{oj} \leq \mathrm{B}' * y_{oj}$$

(3-12)

Constraints (3-7) ensure that there are no inventories in cross-docking centers, which means total income flows to cross-dock centers equal to total outgoing flows from cross-docking center. Constraints (3-8) represent that the total number of products shipped form the terminal do not excess the total supply of the terminal. Constraints (3-9) make sure the total amount of products delivered to distribution centers satisfy the demand of distribution centers. Constraints (3-10) means the intershipment time of replenishment cycles do not excess the maximal time the products allowed to stay in distribution centers, and delivery frequencies do not excess once per day. Constraints (3-11) and constraints 3-12) mean that the quantities of shipments should not excess the capacity of both reefer container trucks and smaller refrigerated trucks.

### *3.3 Solution method*

Since the non-linear programing models are too complicated to be solved in this stage, we propose a simulation method to estimate the results of the models. We simulate the models with different frequencies and select the optimal result for two models with the minimal total transport and inventory costs. Because distribution centers open 24 hours every day, replenishment cycles are not necessary integer. However, the replenishment frequency should be integer and not excess the once per day. We determine the appropriate distribution strategy by comparing the objective value for two models to find the solution with minimum costs.

### *3.4 Expected results*

1. Demand

Table 2.3 shows that direct shipping is more suitable when demand is high, especially when demand is high enough to ship products in full-truck-load (FTL). When demand is relatively low, products are shipped in less-than-truck-load (LTL). In this case, cross-docking allows product consolidation and increase the utilization of trucks and reduces the transport costs. Therefore, if demand is lower than the capacity of the trucks, cross-docking is more suitable, and vice versa. Besides, table 2.3 also indicates that direct shipping is more suitable when demand rate is unstable and with unbalance demand and supply. In this case, information can be directly passed from distribution centers to the terminals without third parties, so terminals can quickly response to the fluctuated demand.

2. Variable transport costs

Table 2,3 shows that cross-docking is more suitable when original-destination pairs have long travel distance. By using cross-docking, products are unloaded from reefer container trucks and loaded to inland refrigerated trucks after consolidation. If the gap of the costs for two type of vehicles is high or travel distance of outbound inland refrigerated trucks is long, variable transport costs are largely reduced by the usage of inland refrigerated trucks.

3. Inventory costs

Table 2.3 also shows that cross-docking is more suitable when inventory weight high. If the inventory costs for the products are relatively high, the inventory level should be low, so products should be shipped in high frequency and with low quantity. As cross-docking could increase the delivery frequency without increase the delivery quantity, cross-docking is more suitable when inventory costs are high. Normally, inventory costs for perishable products are higher than that for other products. Longer the products were stored, higher degradation of the perceived value and freshness of the products.

4. Maritime transport cost rate

Because of the high freight rate, maritime transport costs account for high proportion of total costs of the supply chain. If the freight rate is lower, it does not matter to reduce the inventory level while shipping products with less-than-truck-load (LTL) and in high delivery frequencies. Cause supplier can quickly response to the fluctuation of demand by using direct shipping, direct shipping is more suitable when freight rate is low. However, when freight rate is high, cross-docking is more suitable. Because of the products consolidation, total number of reefer containers used and maritime transport costs are largely reduced by using cross-docking.

## Chapter 4 Case study

In a distribution system for perishable products, regional distribution centers are commonly used to consolidate and supply products to diverse locations in a particular administrative or geographic region (Federgruen, et al., 1986). In this section we will implement the proposed models on a case that is inspired by the perishable food distribution from port of Rotterdam to distribution centers of Albert Heijn in the Netherlands.

### *4.1 Description and data*

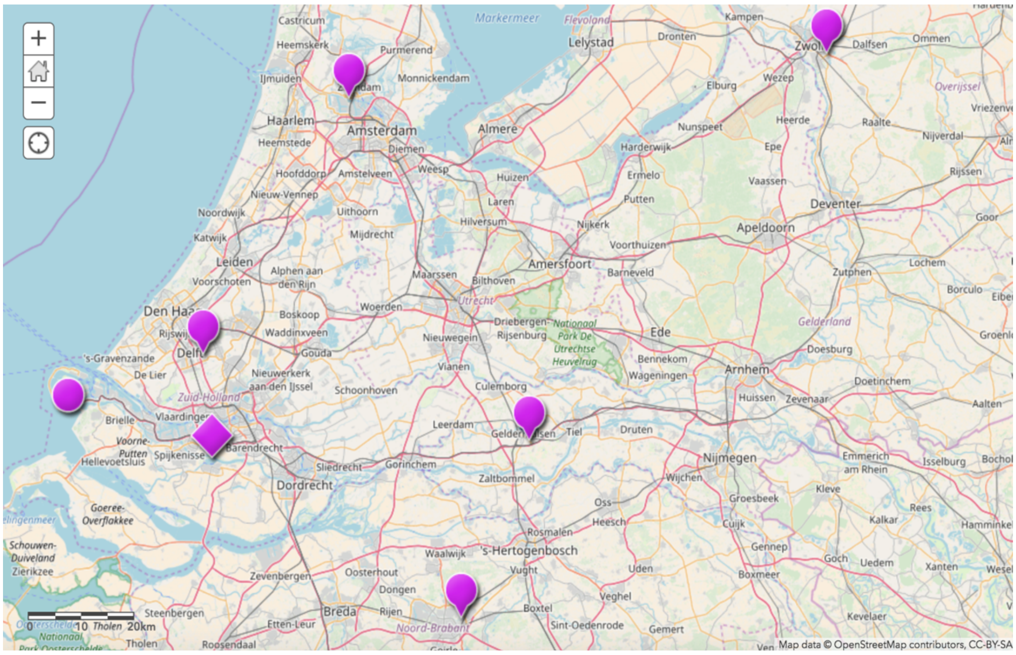


*Figure 4.1 Locations of both facilities*
Source: (Logistiek, 2018)

The underlying distribution network presented in figure 4.1 consists of one container terminal in port of Rotterdam, five distribution centers of Albert Heijn, and one cross-dock center of Kloosterboer who offers a huge range of added-value service such as cold storage, cargo inspections, and repackaging in its cross-dock center (portofrotterdam, 2018). The container terminal is located in Maasvlakte, and the cross-dock center is on the City Terminal site in the Eemhaven. The distribution centers are located in Geldermalsen, Pijnacker, Tilburg, Zaandam and Zwolle (Logistiek, 2018). We use ArcGIS to analyse the distances between terminal, cross-dock center, and distribution centers listed in table 1. Figure 4.2 and Figure 4.3 show the routes of each distribution strategy separately.

*Table 4.1 Distances between terminal, cross-dock center, and distribution centers*

| Distance | | Terminal | Cross-dock center |
|---|---|---|---|
| Cross-dock center | | 37.3km | - |
| Distribution center | Geldermalsen | 101.1 km | 66.2km |

| | | | |
|---|---|---|---|
| | Pijnacker | 46.2km | 20.8km |
| | Tilburg | 115.5km | 80.7km |
| | Zaandam | 110.2km | 86.5km |
| | Zwolle | 187.1km | 157.8km |

Source: (Logistiek, 2018)

*Figure 4.2 Routes for direct shipping*
Source: (Logistiek, 2018)

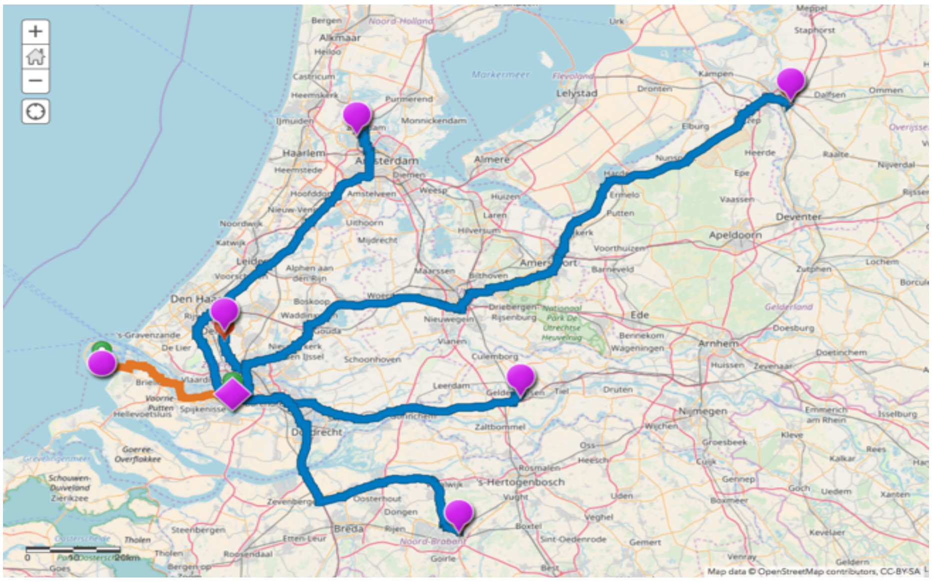

*Figure 4.3 Routes for cross-docking*
Source: (Logistiek, 2018)

There are two types of vehicles used. Reefer container trucks are utilized in direct shipping strategy and inbound short-haul routes in cross-docking strategy from the terminal to cross-dock center. Smaller refrigerated trucks are utilized in cross-docking strategy for the deliveries between cross-dock center and distribution centers. The parameters used to calculate the vehicles capacity are taken from Soysal, et al., (2015). The capacities of reefer container trucks and smaller refrigerated trucks are 27 tonnes and 10 tonnes respectively. We estimate the fixed handling costs, which is

€80 per trip for reefer containers in the terminal and is €100 per trip for small refrigerated trucks in cross-dock center. Since products needed to be unloaded from reefer container trucks, sorted, consolidated, and loaded to refrigerated trucks, fixed handling costs in the cross-dock center are higher than that in the terminal where products are only needed to be loaded to the trucks. The variable transport costs including fuel consumption and driver wages, are assumed and based on Soysal, et al., (2015). They estimate fuel price is €1.7 per litre, and driver wage is €0.18 per minute. As we assume that vehicles travel at a fixed speed which is around 60 km/h, variable costs are decided by the travel distance. Because reefer container trucks are larger and heavier than refrigerated trucks, energy and fuel are consumed more in reefer containers trucks. Therefore, we assume that the variable costs are €1/km for reefer container trucks and €0.7/km for refrigerated trucks. However, as the empty reefer container trucks and refrigerated trucks should return to terminal and cross dock center, the variable costs of each shipment should be double.

Different types of perishable food have different characteristics and storage conditions such as temperature and humidity condition, so different types of perishable food should not be stored and shipped together. In this thesis, we only consider transport one type of perishable food, which is banana. As the most favoured fruit in the world, bananas are harvested and traded through the whole year, so the bananas trades have little seasonality. With only two to three weeks shelf life, bananas are normally stored in the distribution centers for maximal one week (Chen & Notteboom). Accounting for 31%, European Union was largest banana importer in the world in 2015, and the growth of gross imports by European Union was 3 percent in 2015 (Fao.org, 2016). Therefore, We believe that the import of banana in European Union will continuously grow in the future. In the Netherlands, banana imports also grew dramatically. In 2016, banana was the third most imported fruit by the Netherlands by import value, following grapes and avocados. 388 million euros of banana was imported by the Netherlands in 2016, compared to 161 millions euros in 2008 (Cbs.nl, 2017).

In 2016, total 388 million euros of banana were imported to the Netherlands (Statista, 2018). Figure 4.4 shows that banana were imported mostly from Latin America and Western Europe. Over 63% of banana were imported from countries in Latin America where banana were produced and grown. Normally it takes 10 to 14 days to deliver products from the Latin America to port of Rotterdam by maritime. The freight rate of a reefer container from Latin America to port of Rotterdam is around €4,000 to €7,000 (Worldfreightrates, 2018). Beside, freight rate from Central America is relatively lower than that in South America, and large percentage of bananas are from Central America. In this case, we use €5000 as assumption for the maritime transport rate. Western European countries were also main importers, accounting for nearly 37%. However, Western European countries are not the suppliers of banana. Banana were imported from Western European countries such as Belgium and Germany, and then transferred to the Netherlands by trucks or barges. Figure 4.5 shows the percentage of banana importers to the Netherlands (Atlas.media.mit.edu, 2018).

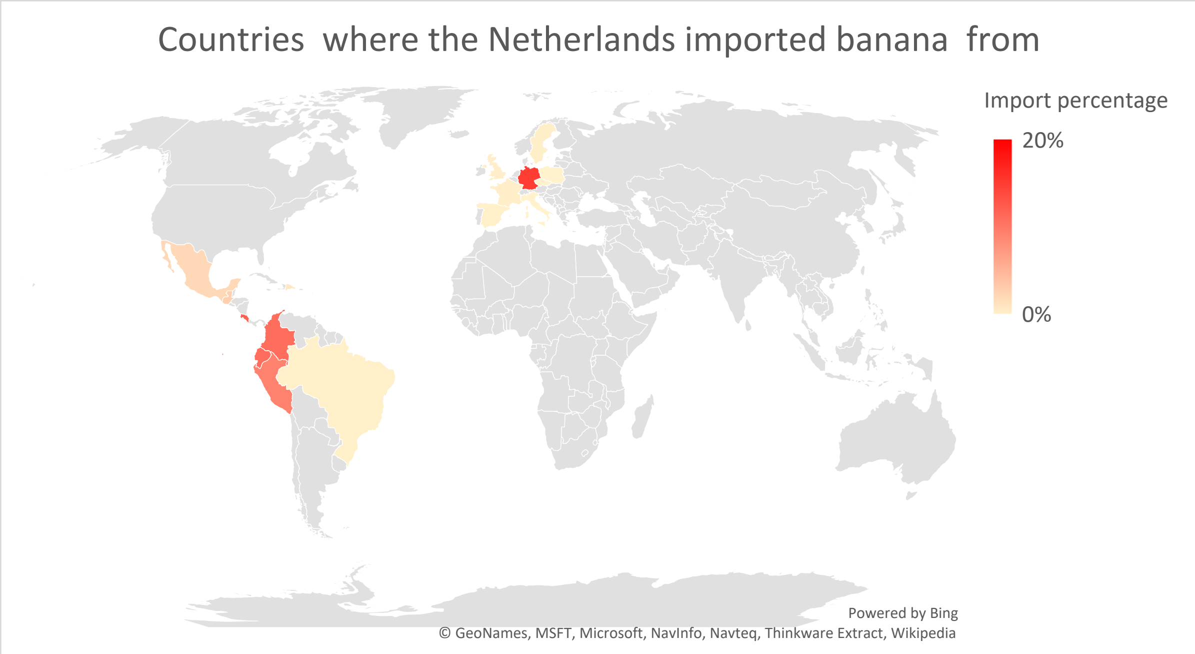


*Figure 4.4 Geographic distribution of banana importers to the Netherlands*
Source (Atlas.media.mit.edu, 2018)

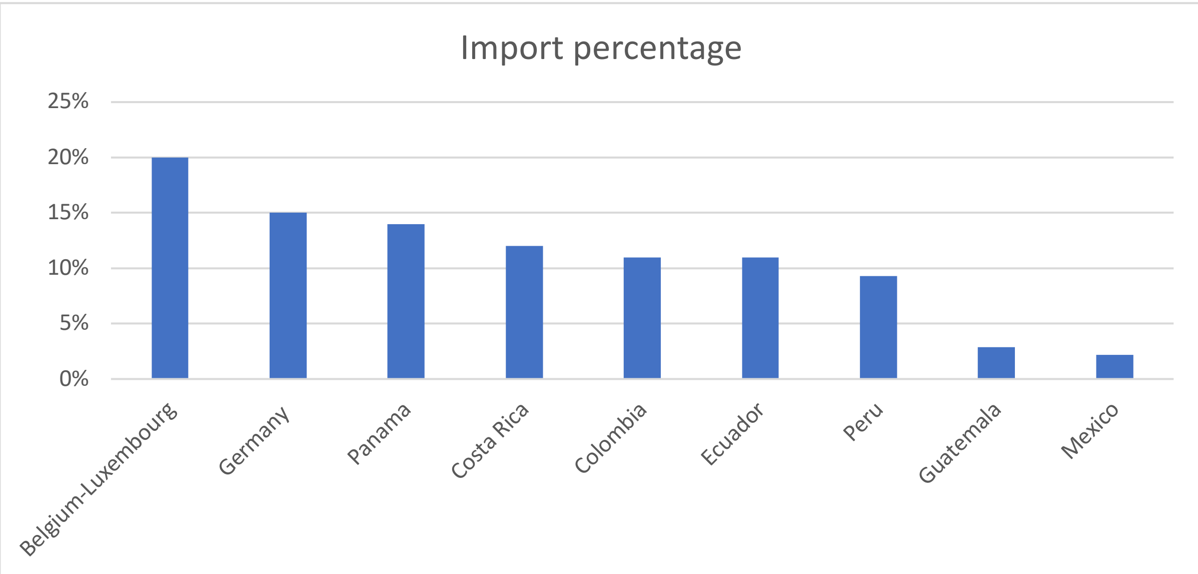


*Figure 4.5 The percentage of banana importers to the Netherlands*
Source (Atlas.media.mit.edu, 2018)

In 2016, total 356 million euros of banana were exported from Netherlands (Statista, 2018). Figure 4.6 shows that nearly 98 % of banana were exported to European Union (Atlas.media.mit.edu, 2018). It means that huge amount of banana were distributed to inland Europe via trucks or barges after being exported to the Netherlands.

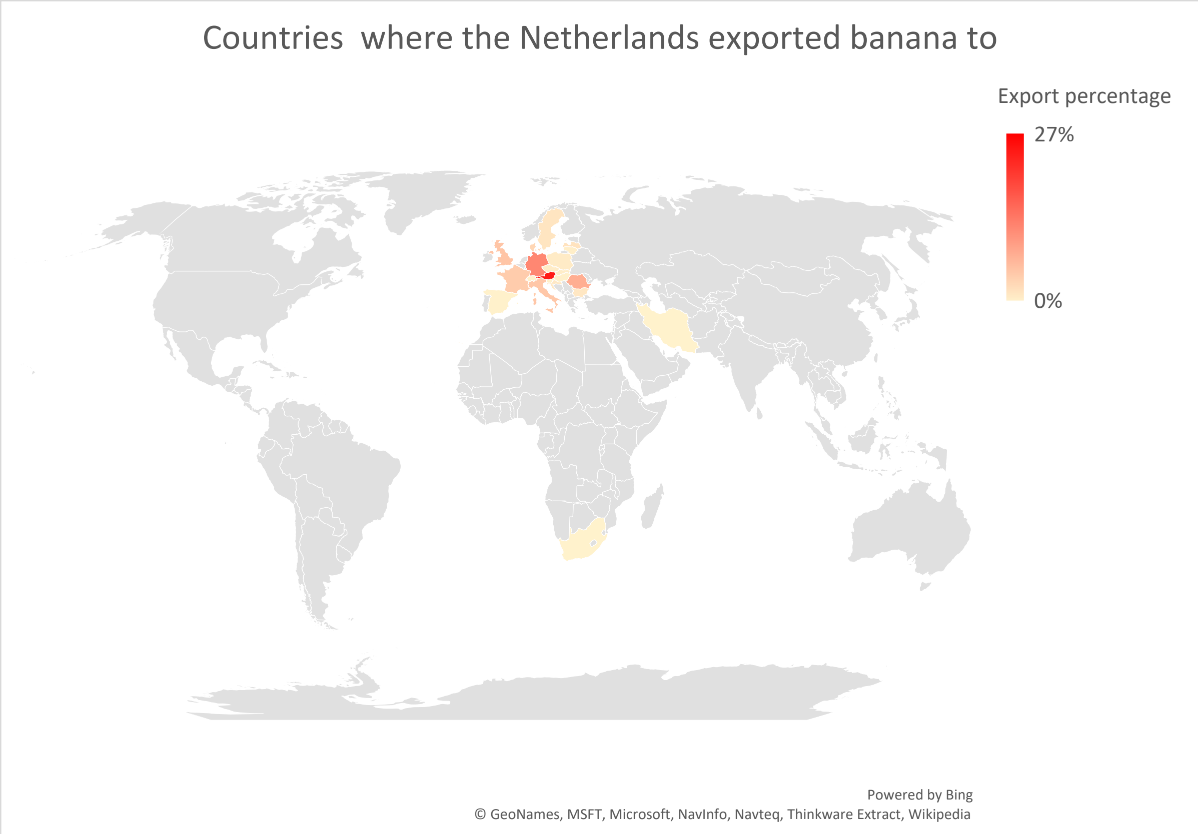


*Figure 4.6 Geographic distribution of banana exporters from the Netherlands*
Source (Atlas.media.mit.edu, 2018)

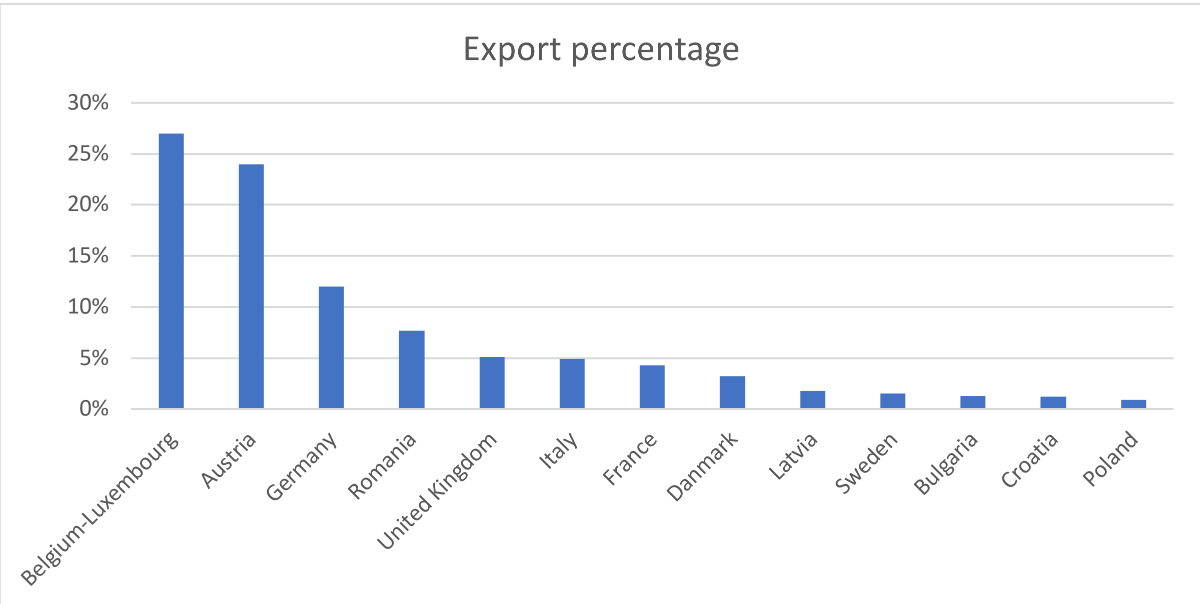


*Figure 4.7 The percentage of banana exporters from the Netherlands*
Source (Atlas.media.mit.edu, 2018)

Figure 4.8 shows the value of import and export bananas in the Netherlands between 2008 and 2016. It shows that either the import value or export value have increased dramatically since 2012. Figure 4.8 also summarizes the trade balance of bananas. Although the trade flow increased, the trade balance of bananas in the Netherlands was relatively stable over the years. The mean of the trade balance from 2008 to 2916 was €56 million with €20.4 million standard deviation.

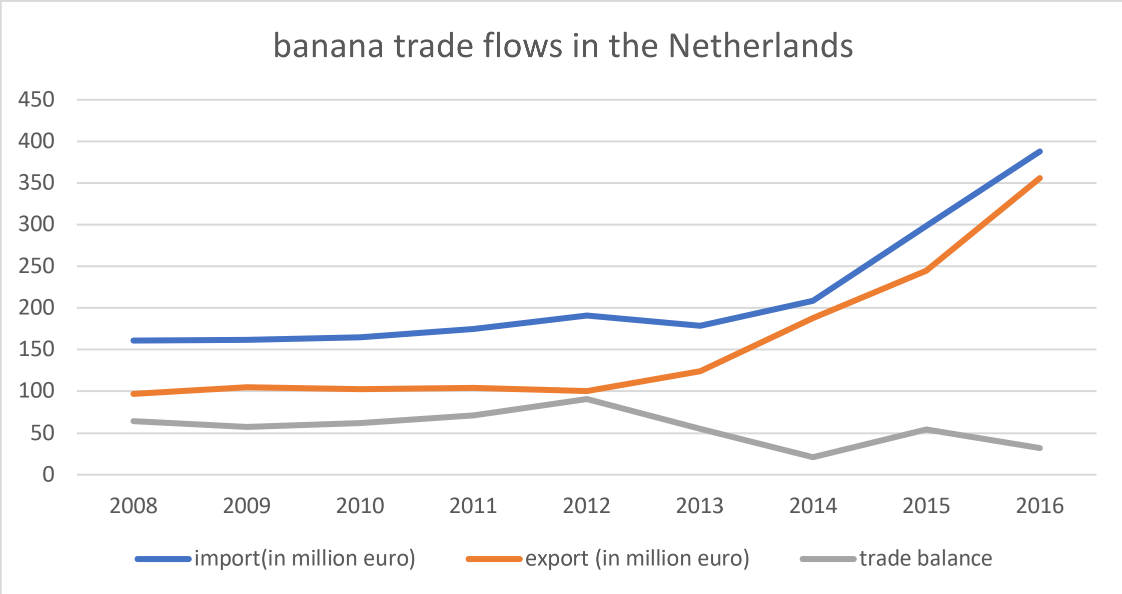


*Figure 4.8 Trade value of banana in the Netherlands*
Source (Statista, 2018).

(Dekker, 2014) estimates the reefer cargo modal split in 2012, and shows that 47% of bananas were transported by reefer containers. Because Port of Rotterdam captures the highest percentage of market share in the Netherlands, we assume that 70% of the trade balance in the Netherlands were imported to port of Rotterdam and delivered to the local markets. Because of the increasing demand for one-stop-shopping, market share of fresh fruits in supermarkets is continuously growing. Market share of fruits in supermarkets accounted for 74 % in 2008 (Apeda.in, 2008). Therefore, we predict that market share of fruits in supermarkets reached 80% in 2018. Figure 4.10 shows that market share of Albert Heijn in supermarket retail were growing, reaching 35.2 % in 2016 (Statista, 2018). Based on the trend, we forecast that the market share of Albert Heijn will reach 35% in the future. As a result, we predict that there are 5.2 million Euros of banana were delivered from port of Rotterdam to Albert Heijn.

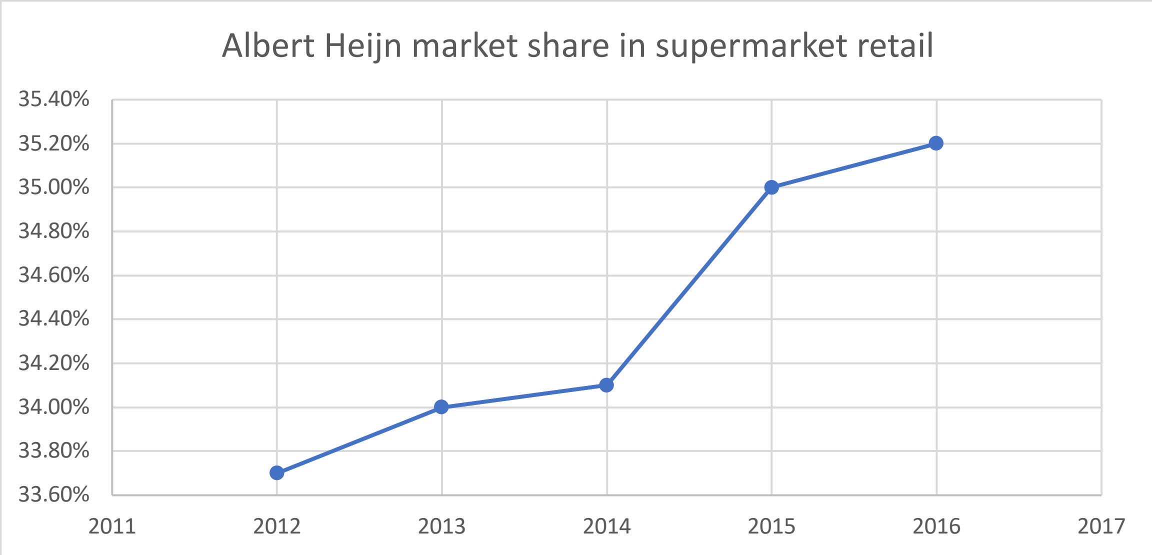


*Figure 4.9 The market share of Albert Heijn in supermarket retail*
Source (Statista, 2018)

Figure 4.10 shows the consumer prices of banana in the Netherlands from 2000 to 2017. The mean of banana consumer price in the Netherlands was €1.58 per kg with €0.089 per kg standard deviation. It shows that the consumer price bananas is relatively stable over the years. Besides, Figure 4.11 shows the share of consumer price for bananas produced in Ecuador and exported to the Netherlands in 2015. The trade value included cost of inputs, labour costs, small-scale farmers, processors/traders, as well as shipping and import costs. Since the importer captured the largest share of end consumer price shown in figure 4.10, we assume the tariffs were largely paid by importers and were excluded in trade value. The trade value accounts for 39.2% of end consumer price of bananas in 2015. Because the trend to fairly distributed consumer price along the supply chain (Oxfamnovib.nl, 2018), we assume that in 2018 trade value would account for 40% of consumer price of banana in the Netherlands. The mean of banana consumer price in the Netherlands is €1.58 per kg shown in figure 4.10, so the trade value of banana in 2018 would be around €0.63 per kg.

We mentioned above we predict that 5.2 million Euros with 0.19 million Euros standard deviation of bananas will be delivered from port of Rotterdam to Albert Heijn. In volume, around 8,200 tons banana were delivered to Albert Heijn. We assume that banana were evenly distributed every week to each distribution center. Therefore, we forecast the banana delivery from port of Rotterdam to each distribution center in Albert Heijn will be around 31 tonnes per week, with standard deviation of 11 tonnes.

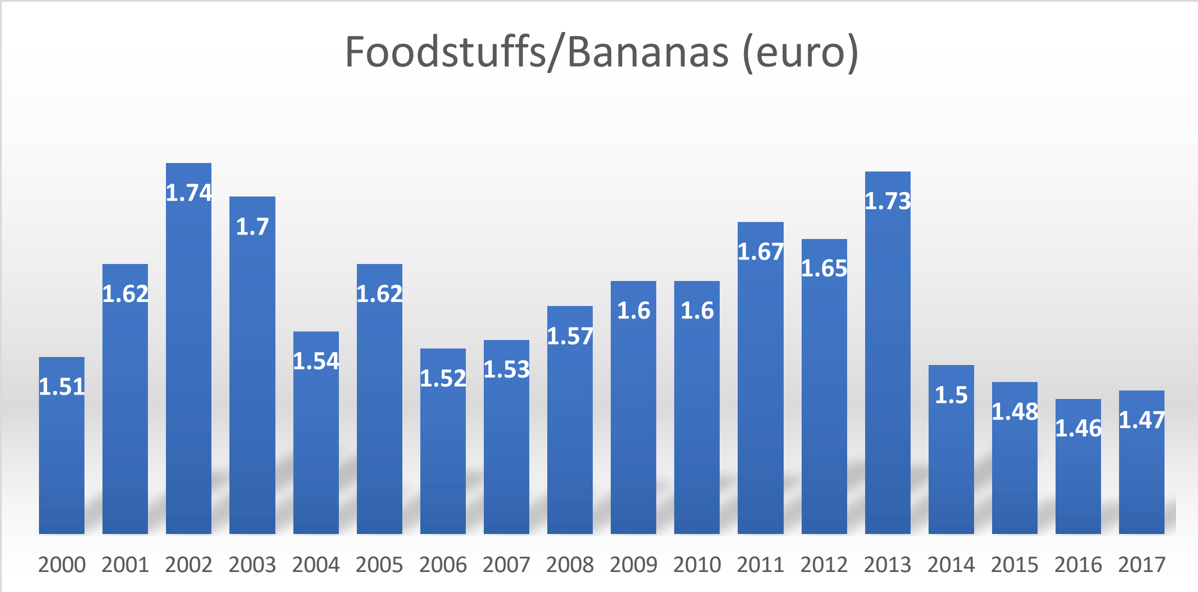


*Figure 4.10 Consumer prices of banana in the Netherlands*
Source : (CBS, 2018)

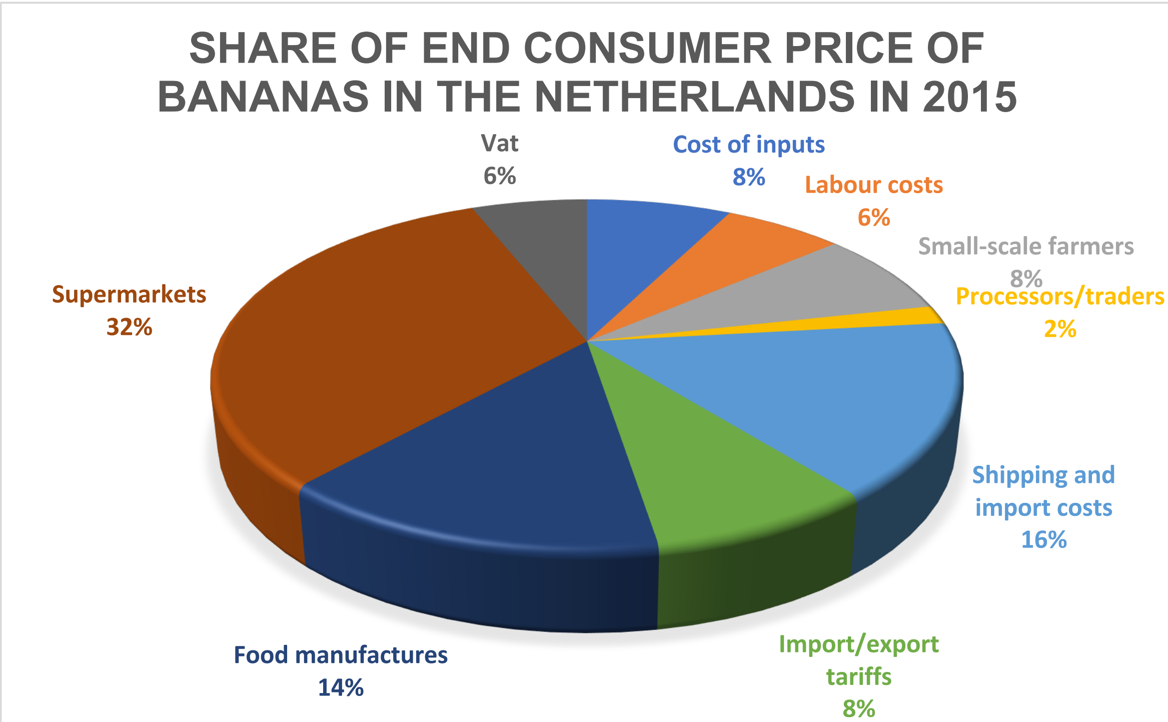


*Figure 4.11 Share of end consumer price of bananas in the Netherlands in 2015*
Source (Oxfamnovib.nl, 2018)

On the other hands, according to figure 4.10, 95 percent confidence interval of banana prices in T-test are from €1.54 per kg to €1.63 per kg. As we assume that the perishable product has fixed shelf life, and the quality degradation and value loss for a perishable product is gradual over its shelf life. So, at the end of the shelf life of a perishable product, the product is no longer able to be sold and the value of that product would be zero. In this case, the holding cost for bananas equals to their consumer prices divided by their shelf life time, which is two to three weeks (Chen & Notteboom). In terms of bananas, the holding costs for bananas in the distribution centers of the Netherlands are from €0.0733 per kg per day to €0.1163 per kg per day.

*Table 4.2 Summary of the parameters for calculation of maritime transport costs*

| | |
|---|---|
| Freight rate of a reefer container | €5,000 per trip |

Source: (Worldfreightrates, 2018)

*Table 4.3 Summary of the parameters for calculation of two types of vehicles*

| Type of vehicle | capacity | Fixed handling cost | Variable costs |
|---|---|---|---|
| Reefer container truck | 27 tonnes | €80 | €1/km*2 |
| Refrigerated truck | 10 tonners | €100 | €0.7/km*2 |

Source: (Soysal, et al., 2015) & Own estimation

*Table 4.4 Summary of the parameters for calculation regarding variable transport costs to different locations*

| Variable costs | | Terminal | Cross-dock center |
|---|---|---|---|
| Cross-dock center | | €74.6 | - |
| Distribution center | Geldermalsen | €202.2 | €92.68 |
| | Pijnacker | €92.4 | €29.12 |
| | Tilburg | €231 | €129.12 |
| | Zaandam | €220.4 | €121.1 |
| | Zwolle | €374.2 | €220.92 |

Source: (Logistiek, 2018), (Soysal, et al., 2015) and Own estimation

*Table 4.5 Summary of the parameters for calculation regarding bananas*

| Parameters | Banana |
|---|---|
| Shelf life time | 2-3 weeks |
| Holding costs | €73.3 per ton per day to €116.3 per ton per day. |
| Maximal shelf time in distribution center | One weeks |
| Mean of weekly demand in each distribution center | 31 tonnes |
| Standard deviation of weekly demand in each distribution center | 11 tonnes |

Source: (Chen & Notteboom) & (Statista, 2018)

## *4.2 Results and discussion*

The models proposed on section 3 will be solved with case study data mention above. We use €73.3 per ton per day as the holding cost rate in the scenario. As the models are non-linear programming, and it is too complicated for us to solve the non-linear programming at this stage, we propose a simulation to estimate the optimal value. we firstly solved the models by determining the total maritime transport, delivery and inventory costs for each distribution centers in different frequencies. Based on formula (3-4) and (3-10), duration of each replenishment cycle should more than one day and less than maximal duration, which is 7 day. Since the delivery frequencies should be integer, we simulated delivery frequencies between once per week to 7 times a week. Then, we selected the minimal transport and inventory costs for five distribution centers as the optimal solutions, and summed up the total costs as the minimal costs for two models. The results show that the total maritime transport, delivery and inventory costs present in parabolic regarding different delivery frequencies.

### *4.2.1 Results*

We simulated the results by the method mentioned above. The distribution of total costs regarding delivery frequencies for five distribution centers are the same. Total costs are parabolic distributed among delivery frequencies. Figure 4.12 shows the sum of total maritime transport, delivery and inventory costs for five distribution centers in different delivery frequencies when five distribution centers are in the same delivery frequencies. The results show that total maritime transport, delivery and inventory costs for five distribution centers are lowest when delivery frequency is two times a week. In this case, 15.5 tons of bananas are delivered in one container each time. The intershipment time for each replenishment cycle is 3.5 days. That means distribution centers would replenish bananas at the end of every 3.5 days.

Capturing the higher percentage of total costs, maritime costs are extremely high when delivery frequencies are high. When delivery frequencies are high, the total number of reefer container used is high. So, apart from maritime costs, fixed costs and variable costs also increase steadily when delivery frequencies improve. However, holding costs are largest reduced while increasing delivery frequencies. In high delivery frequencies, delivery quantities are low and the intershipment time of replenishment cycle is low also. The inventory level of banana in distribution centers can be lower as a result.

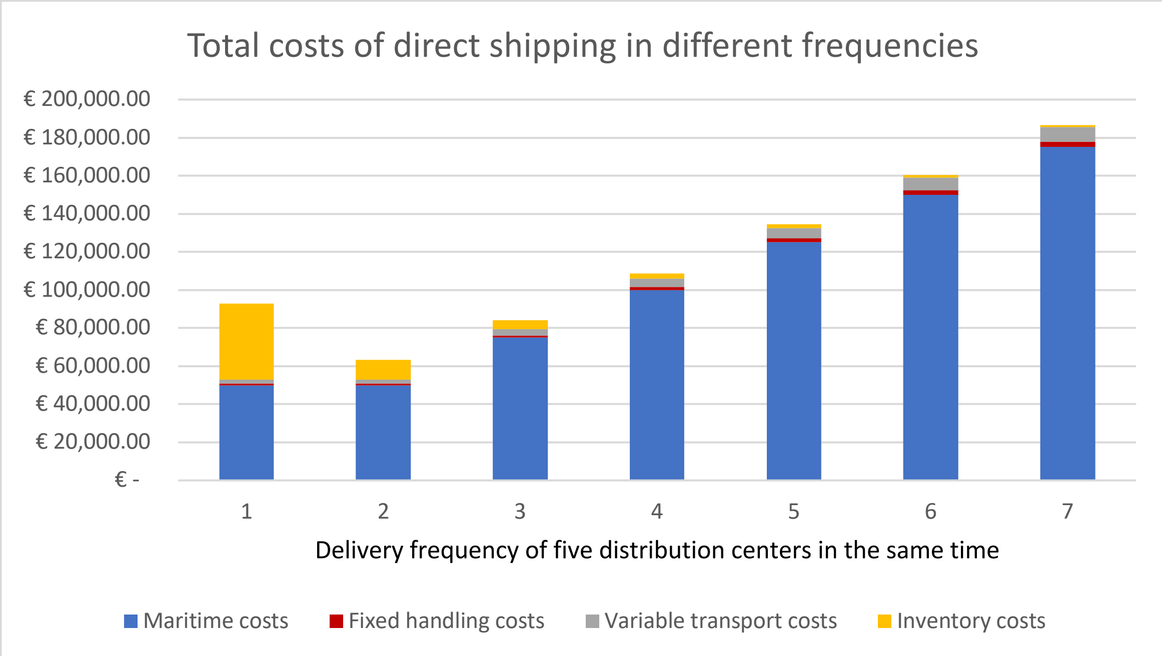


*Figure 4.12 Total costs of direct shipping in different frequencies*
Source: Own elaboration

We use formula (3-6) to (3-13) to simulate the results in cross-docking. In case of cross-docking, the optimal result occurs when delivery frequencies of five distribution centers are the same, so that products can be seamless transferred from inbound reefer container trucks to outbound refrigerated trucks without inventory in cross-dock center. Figure 4.13 shows the total costs of five distribution centers in seven simulations when delivery frequencies of five distribution are same. It shows that maritime transport costs are relatively high when delivery frequencies are 4 and 5 times a week. Because of the demand rate and capacity of reefer container, minimal total number of reefer containers used in a week is 6 reefer containers. If delivery frequencies are 4 and 5 times a week, total two containers should be utilized for in one replenishment cycle, and total 8 and 10 reefer containers used in a week. In this case, maritime transport is not efficient, as bananas are shipped in less-than-truck-loaded (LTL) and in relatively high delivery frequency. However, when delivery frequency is 6 times a week, only one reefer container is used in a replenishment cycle, and total 6 reefer containers used in a week.

When demand is constant, the optimal delivery frequency for cross-docking is in 6 times a week. In this case, 25.8 tons of bananas are shipped from the terminal to the cross-dock center directly 6 time a week with 1.16 days intershipment time of a replenishment cycle. By using cross-docking, delivery quantity in maritime transport is close to the capacity of reefer container. Maritime transport would be more efficient, as the reefer containers could be fully utilized. After being sorted and consolidated, bananas are directly shipped from the cross-dock center to each distribution center with one refrigerated trucks carrying 5.17 tons of bananas. Since the intershipment time of replenishment cycle is lower and the delivery quantity to distribution centers are lower also,  inventory costs and inventory level in the optimal results is low.

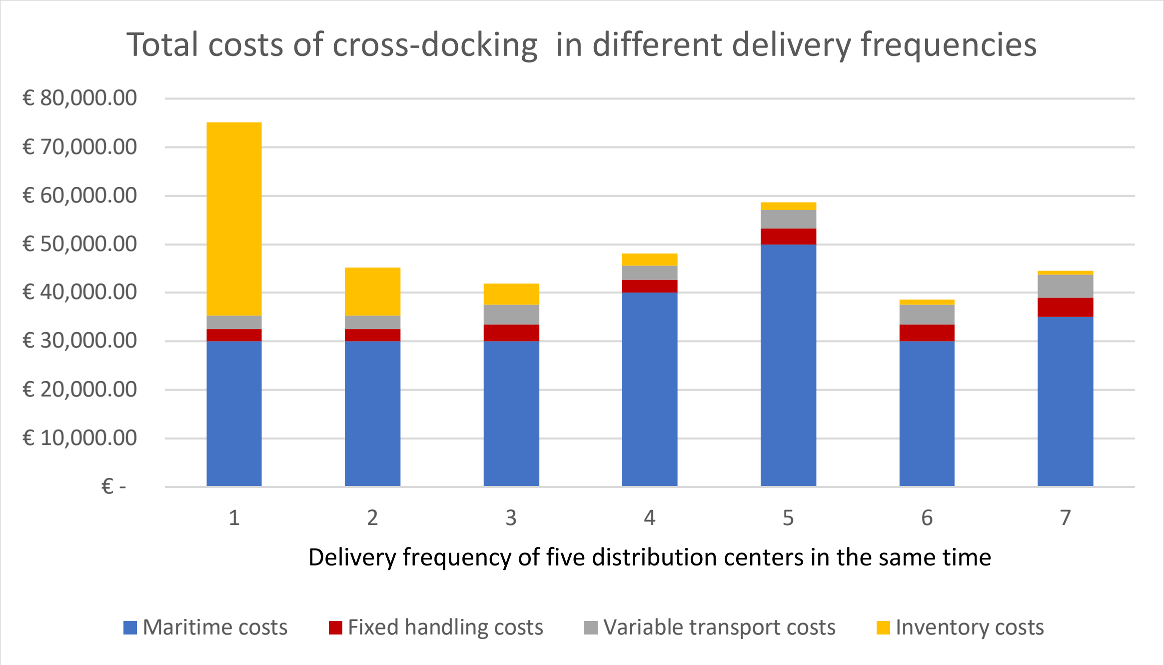


*Figure 4.13 Total costs of cross-docking  in different delivery frequencies*
Source: Own elaboration

Figure 4.14 summarizes the costs for optimal solutions in two distribution strategies. It shows that cross-docking is more suitable in this case, as total costs for direct shipping are extremely higher than that for cross-docking. Total maritime transport, delivery and inventory costs in direct shipping is 24.7 thousand Euro more than total costs in cross-docking. Almost 40 % of total cost are reduced by using cross-docking. Because of the high freight rate of reefer container, maritime costs capture the highest percentage of total transport and inventory costs. Since the perishable characteristic of bananas, holding cost rate for banana is higher than normal products. Inventory costs account for the second largest part of total maritime transport, delivery and inventory costs in direct shipping, as the intershipment time of replenishment cycle is longer and inventory level is large in direct shipping than in cross-docking.

By using cross-docking total number of reefer containers used are largely lower and the containers can be fully utilized. Since the freight rate of reefer container is high, maritime costs are reduced by 40% while using cross-docking. On the other hand, cross docking significantly improves the delivery frequency, as bananas can be consolidated in a reefer container firstly, then distributed to distribution centers by small refrigerated trucks. Therefore, inventory costs can be greatly reduced.

However, fixed handling costs and variable costs are higher in cross-docking than that in direct shipping. In cross-docking total number of vehicles used, including reefer container trucks and refrigerated trucks is more than that in direct shipping. Besides, in cross-docking fixed handling costs consist of handling costs not only in the terminal but also in the cross-dock center. Since bananas are needed to be unloaded, sorted, consolidated and loaded in the cross-dock center, handling costs in the cross-dock centers are higher than that in the terminal, where products only needed to be loaded into trucks. As a result, fixed costs are much higher and account for higher percentage of total costs in cross-docking than that in direct shipping. Although the variable cost rate for small refrigerated trucks are lower than reefer containers trucks, number of vehicles used in cross-docking is greatly more than that in direct shipping. The the variable costs increasing for refrigerated trucks outweigh the variable costs reducing for reefer container trucks.

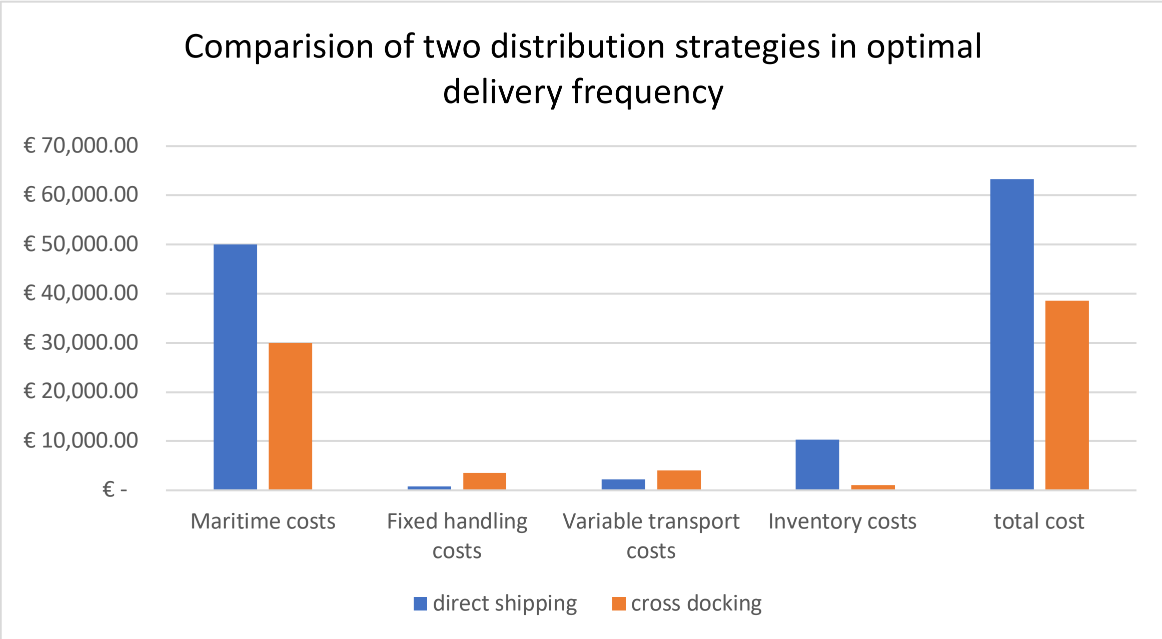


*Figure 4.14 Summary of costs of two models in optimal delivery frequency*
Source: Own elaboration

### 4.2.2 Discussion

Section 4.2.1 show that optimal distribution strategy for delivery of bananas from port of Rotterdam to distribution is cross-docking. By using cross-docking, bananas are delivered in high frequency, which is 6 times a week. The intershipment time of replenishment cycle is largely lower in cross-docking than in direct shipping. So, not only inventory costs are largely reduced, but also loss of freshness can be greatly improved by using cross-docking. The display time of bananas in Albert Heijn would be longer in this case, and customers are more willing to buy the fresh bananas. Furthermore, after being sorted the cross-dock center and delivered in small refrigerated trucks, delivery quantities to five distribution centers are much lower. Then, inventory level in cross-docking is much lower than that in direct shipping, that would largely reduce storage area in distribution centers.

Reefer containers can be fully utilized in cross-docking. Since bananas are consolidated in reefer containers, bananas are shipped from the terminal to the cross-dock center in nearly full-truck-load (FTL). So, maritime transport will be more efficient. Besides, the travel distance for reefer container trucks are shorter also. Variable transport costs for reefer containers are greatly reduced and the turnover rate for reefer container trucks can be enhanced as a result. Cross-docking largely decrease the risk to pay the detention fee for late returning reefer containers.

However, in terms of transport lead time, the time spent to delivery products from the terminal to distribution centers though cross-docking are longer than that though direct shipping. By using cross-docking, products should be sorted, consolidated and temporarily stored in the cross-dock centers. Since, we do not consider pipeline holding costs in our objective, the transport lead time does not affect the results. In reality, service time in the cross-dock center is also an import elements needed to considered.

In conclusion, cross-docking is more appropriate distribution strategy for delivery banana from port of Rotterdam to distribution centers of Albert Heijn, because nearly 40% of total maritime transport, delivery and inventory costs are reduced while using cross-docking. By using cross-docking maritime transport is more efficient as reefer containers can be fully utilised in full-truck-load (FTL). On the other hand, as the intershipment time in each replenishment cycle is reduced by using cross-docking, the quality degradation of banana can be improved. Banana, that are distributed from distribution centers to customers, are able to maintain their freshness and attach more customers. However, in reality demand of banana are not constant over times. As a result, in next section we plan to simulate the case when the demand is uncertain. Besides, since the value of demand rate and parameters greatly differ the results also, we will do sensitive analyses to determine the effects of demand rate and parameters respectively.

## Chapter 5 Computational study

In previous sections, we solved the models when the demand is known and constant. However, in reality demand is stochastic and difficult to predict. As a result, in this section we will carry out a computational study to test the result when demand is uncertain. Besides, we will do sensitivity analyses to test the impacts of demand parameters.

The aims of two models are to minimize the sum of maritime transport, delivery and inventory costs while satisfying all demands from distribution centers in certain service level. Our experiments are based on periodic policy that orders are made on several frequencies with constant intershipment time (Bertazzi, et al., 2000) and the deliver-up-to-level policy mentioned in (Crama, et al., 2018). In deliver-up-to-level policy, any customer sets a maximal inventory level, and inventory plus delivery quantity in each replenishment cycle should not excess the maximal inventory level. Since the perishable products cannot be stored for a long time, there is no safety stock in our models. Based on delivery frequencies, the weekly planning horizon is divided into various discrete time intervals named replenishment cycles. That means the intershipment time of replenishment cycles are different and decided by delivery frequencies. We define the intershipment time of replenishment cycle as $\gamma$. For each $\gamma \leq \mathrm{L}$ period, distribution centers make orders to the order-up-to-level $q_{ij}$. $\mathrm{L}$ is the maximal time for a product to be stored in a distribution center, that is one week in this case. $q_{ij}$ is the minimal number of products that should be sufficient to buffer the demand in next $\gamma$ period. The order-up-to-level $q_{ij}$ is decided by the demand, intershipment time of each replenishment cycle, and customer service level. Because bananas are harvested and traded through the whole year, demand of bananas is relatively constant with little seasonality around the year (Chen & Notteboom). Therefore, we assume the weekly demand of bananas in 2018 is normal distribution. We use equation (5-1) to calculate the $q_{ij}$ based on normal distribution demand and required customer service level (CSL) (Chopra & Meindl, 2013). According to Chopra & Meindl, (2013) customer service level (CSL) is the fraction of replenishment cycles in which all the customer demands are met and equals to the probability of not having a stockout in a replenishment cycle. Equation (5-2) and equation (5-3) show the formula to calculate the expected demand and standard deviation during a replenishment cycle (Chopra & Meindl, 2013). $\gamma$ represents the replenishment cycle and $\mathrm{f}$ means the delivery frequency. Table 1 shows the relation between frequencies, expected demand during each period and standard deviation of demand in each period.

$$\text{Probability}\left(\text{Demand during }\gamma \leq\ q_{ij}\right) = \text{CSL} \tag{5-1}$$

$$\text{Expected demand during }\gamma = \frac{1}{\mathrm{f}} * \textit{Average weekly demand}, \tag{5-2}$$

$$\textit{Standard deviation of demand during }\gamma = \sqrt{\left(\frac{1}{f}\right)} * \text{Standard deivation of weekly demand}$$

(5-3)

*Table 5.1 Expected demand and standard deviation in different delivery frequencies*

| Frequency (times per week) $f$ | 1.00 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 |
|---|---|---|---|---|---|---|---|
| Duration (days) $\frac{1}{f} * T$ | 7.00 | 3.50 | 2.33 | 1.75 | 1.40 | 1.17 | 1.00 |
| Expected demand in different delivery frequency (tons) | 31.00 | 15.50 | 10.33 | 7.75 | 6.20 | 5.17 | 4.43 |
| Standard deviation of demand in different delivery frequency (tons) | 11.00 | 7.78 | 6.35 | 5.50 | 4.92 | 4.49 | 4.16 |

Source: Own elaboration

We implement the computational experiments based on the parameters listed on section 4. In the initial model, we use the minimal holding cost, which is €73.3 per ton per day, as the holding cost rate, so that we can compare the results of computation experiments with the results when demand is constant. For each model, we will simulate the results in different frequencies, and determine the optimal frequency with minimal total transport and inventory costs.

In section 5.1 we will illustrate the steps of computation experiments in Rstudio. Then, in section 5.2 we will show the results of computation experiments in different customers service level and compare the results with that in constant demand. In section 5.3 we will do the sensitivity analyses for various expected demand and standard deviation of demand. In section 5.4 we will test the results by differing the parameters.

## *5.1 Steps for computation experiments*

We use Rstudio to implement the computation experiments for direct shipping and cross-docking separately.

(1) Direct shipping

Step 0. Initialize by setting initial inventory level $I_{ij}$ equals order-up-to-level $q_{ij}$. Average fixed costs $FC_{ij}$, average variable costs $VC_{ij}$, average holding costs $HC_{ij}$, and average total costs $TC_{ij}$ for five distribution centers in different frequencies and in certain CSL equal zero.

Step 1. Generate a random number for one-week demand in each distribution center, based on normal distribution parameters in table 5.1. Next, evaluate the inventory level at the end of each replenishment cycle by initial inventory level $I_{ij}$ minus random demand, and use formula (3-3) to determine delivery quantity of each distribution center in different delivery frequencies. Use formula (3-5) to determine the number of vehicles used to deliver banana to distribution center in different delivery frequencies.

Step 2. Use formula (3-1) to determine the total maritime transport, delivery and inventory costs for five distribution centers in different frequencies of certain CSL. Select the optimal delivery frequency for five distribution centers with minimal total costs and sum up the total costs of five distribution centers.

Step 3. To optimal the average weekly total maritime transport, delivery and inventory costs in one year, we repeat step 1 and step 2 for 52 times and generate the average of 52 experiments.

(2) Cross-docking

Because bananas should be seamless transferred from the cross-dock to distribution centers, delivery frequencies to the cross-dock center and to five distribution centers should be the same in one week.

Step 0. Initialize by setting initial inventory level $I_{ij}$ equals order-up-to-level $q_{ij}$. Average fixed costs $FC_{ij}$, average variable costs $VC_{ij}$, average holding costs $HC_{ij}$, and average total costs $TC_{ij}$ for five distribution centers in different frequencies and in certain CSL equal zero.

Step 1. Generate a random number for one-week demand in each distribution center, based on normal distribution parameters in table 5.1. Next, evaluate the inventory level at the end of each replenishment cycle by initial inventory level $I_{ij}$ minus random demand, and use formula (3-9) to determine delivery quantity of each distribution center in different delivery frequencies. Use formula (3-12) to determine the number of vehicles used delivery banana to distribution center in different delivery frequencies.

Step 2. Use formula (3-6) to determine the total outbound delivery costs and inventory costs for five distribution centers in different frequencies of certain CSL. Use formula (3-7) to determine the quantities of bananas shipped from the terminal to the cross-dock center in different delivery frequencies. Use formula (3-11) to decide the number of reefer container trucks used in different delivery frequencies.

Step 3. use formula (3-6) to calculate total maritime transport, delivery, and inventory costs for one week in different delivery frequencies. Then, determine the optimal delivery frequency for that week with minimal total costs.

Step 4. To optimal the average weekly total maritime transport, delivery and inventory costs in one year, we repeat step 1 to step 3 for 52 times and generate the average of 52 weeks.

## 5.2. Results and analyses

In this part, we will discuss the computational experiments results of the modes proposed in section 3, solved by using Rstudio. We will present a thorough discussion regarding the optimal solutions of in different customer service level and compare them with the result when demand is constant shown in section 4.

Though formula (5-1) we carry out order-up-to-level $q_{ij}$ in different frequency and different customer service level shown table 5.2. It shows that when the required customer service level increase, the order-up-to-level (OUL) increase also. Therefore, inventory level is relatively high when needed customer service level is high. Furthermore, in our simulations, if demand in one period is more than order-up-to-level, the inventory level in that period is zero instead of negative quantity, since we do not consider stock out costs and back order costs.

*Table 5.2 Order-up-to-levels in different frequencies and different CSL*

| Frequency (times per week) | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Duration (days) | 7.0 | 3.5 | 2.3 | 1.8 | 1.4 | 1.2 | 1.0 |
| OUL when CSL=0.80 (in tons ) $q_{ij}$ | 41 | 23 | 16 | 13 | 11 | 9 | 8 |
| OUL when CSL=0.85 $q_{ij}$ | 43 | 24 | 17 | 14 | 12 | 10 | 9 |
| OUL when CSL=0.90 $q_{ij}$ | 46 | 26 | 19 | 15 | 13 | 11 | 10 |
| OUL when CSL=0.95 $q_{ij}$ | 50 | 29 | 21 | 17 | 15 | 13 | 12 |
| OUL when CSL=0.99 $q_{ij}$ | 57 | 34 | 26 | 21 | 18 | 16 | 15 |

Source: Own elaboration

The detailed one-year optimal results by using direct shipping when customer service level is 80% are shown in appendix A. It shows that when weekly demand is low, weekly transport and inventory costs are conversely high. When customer service level is 80%, optimal delivery frequencies for five distribution centers are both two times a week. Therefore, inventory level in this case is high. Inventory level at the end of each replenishment cycle equals to order-up-to-level minus demand in that period. When demand is low, inventory level at the end of the replenishment cycle is high, so one-year average inventory level would be high as a result. Therefore, when demand is uncertain, low weekly demand would result for high total transport and inventory costs, because of the high inventory level.

Figure 5.1 presents the summary of one-year weekly total maritime transport, delivery and inventory costs by using direct shipping when customer service level is 80%. It shows that one-year weekly total maritime transport, delivery and inventory costs tend to be normally distribute, as weekly demand of bananas are random and normally distributed. In this case, average one-year weekly maritime transport, delivery and inventory costs is €72,558 with standard deviation of €1511.

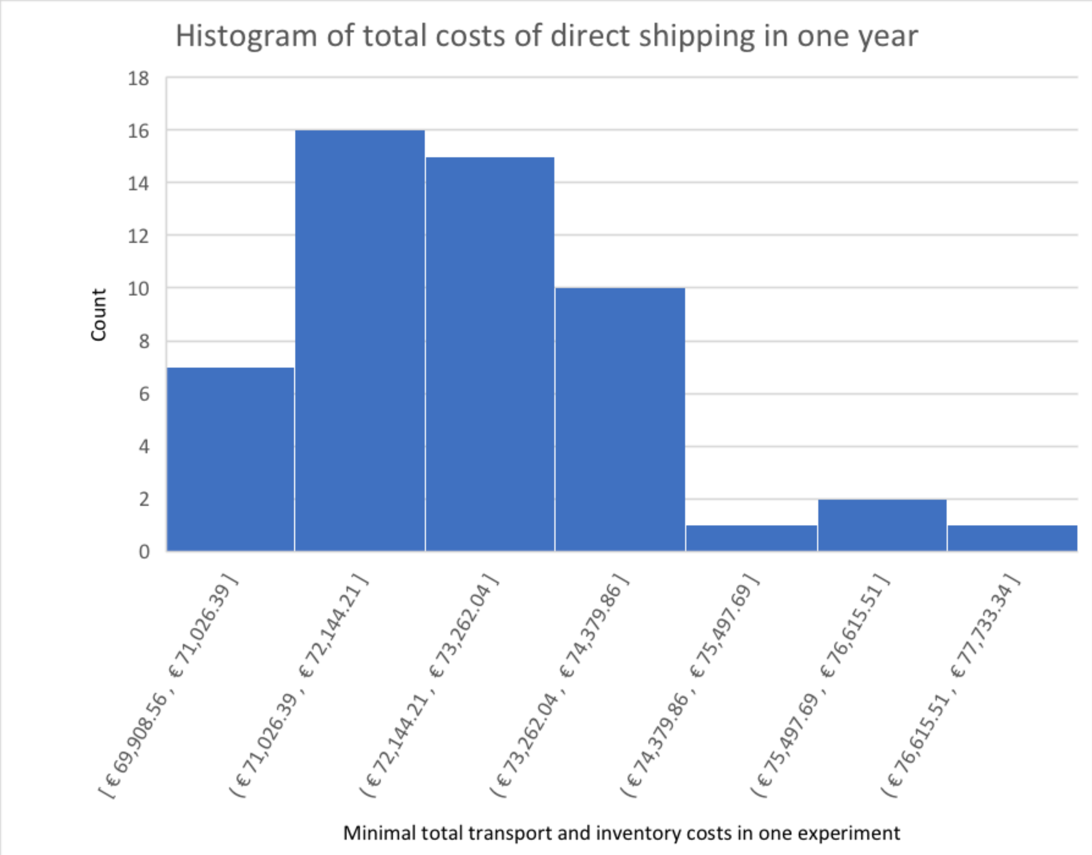


*Figure 5.1 Histogram of one-year total costs by using direct shipping*
Source: Own elaboration

The one-year detailed experiment outcomes by using cross-docking when customer service level is 80% are shown in appendix B, and the summary of the one-year weekly total costs and optimal delivery frequencies are shown figure 5.2 and figure 5.3. In this case, the average one-year weekly maritime transport, delivery and inventory costs is €43,112, with standard deviation of €6054. Figure 5.2 presents the histogram of one-year weekly total maritime transport, delivery and inventory, and figure 5.3 shows the count of one-year optimal delivery frequencies when customer service level is 80%. Because one-year bananas demand is normally distributed, in most of the cases average demands of five distribution centers are around the mean of weekly demand. Therefore, mostly six or seven reefer containers should be used in one week and optimal delivery frequencies in these cases are either six times a week or seven times a week. Total maritime transport, delivery and inventory costs in these weeks are about €38,000 to €41,000 and €45,000 to €46,000.

The detailed experiment outcomes show that there is one extreme week that total maritime transport, delivery and inventory costs is €59,844. In that week, total demand of five distribution centers is the largest demand in one year. Average demands of five distribution centers in that week excess mean plus one standard deviation of weekly demand (42 tons). Since total demand is extremely high, the total number of reefer containers used in that week is more than that in other weeks. Therefore, maritime transport cost in that week is extremely high. In that case, optimal delivery frequency is three times a week, because for whole week total 9 reefer containers should be used. However, inventory level in this case is relatively high also, as the low delivery frequency. Therefore, when demand is extremely high in cross-docking, both maritime transport costs and inventory costs are high.

The detailed outcomes also show that when optimal delivery frequency is four times a week, weekly transport and inventory costs are either from €31,000 to €32,000 or from €51,000 to €54,000. In weeks that delivery frequencies are four times a week, average demands of five distribution centers are relatively low or high. If average demands of five distribution centers are close to mean minus one standard deviation of weekly demand (20 tons), total costs are around €31,000 to €35,000. When demand is low, fewer reefer containers should be used in a week. One reefer container is enough to carry all demands in each replenishment cycle when delivery frequency is four times a week. Therefore, total maritime transport, delivery and inventory costs in these weeks are the lowest. If average demands of five distribution centers are close to mean plus one standard deviation of weekly demand (42 tons), total costs are around from €51,000 to €55,000. In this situation, demand on that week is more than seven times the capacity of reefer containers, and totally 8 reefer containers should be used in one week. When delivery frequency is four times a week, fewest reefer containers are used and lowest inventory are stored in that week. Since more reefer containers should be used in these weeks, maritime transport costs in these weeks are relatively high.

Therefore, the detailed outcomes indicate that when using cross-docking, the optimal delivery frequencies are decided by the actual weekly demand. If weekly demand is less than seven times the capacity of reefer containers, that is 189 tons a week (7*27 tons), then optimal delivery frequency in that week equals round up integer number of the weekly demand divided by the capacity of reefer containers. For example, if total demand in one week is 150 tons, optimal delivery frequency in that week is 6 times a week (round up 150 tons/27 tons). If weekly demand is more than seven times the capacity of reefer containers, total number of reefer container used in whole week. Higher demand in a week would result for lower delivery frequency.

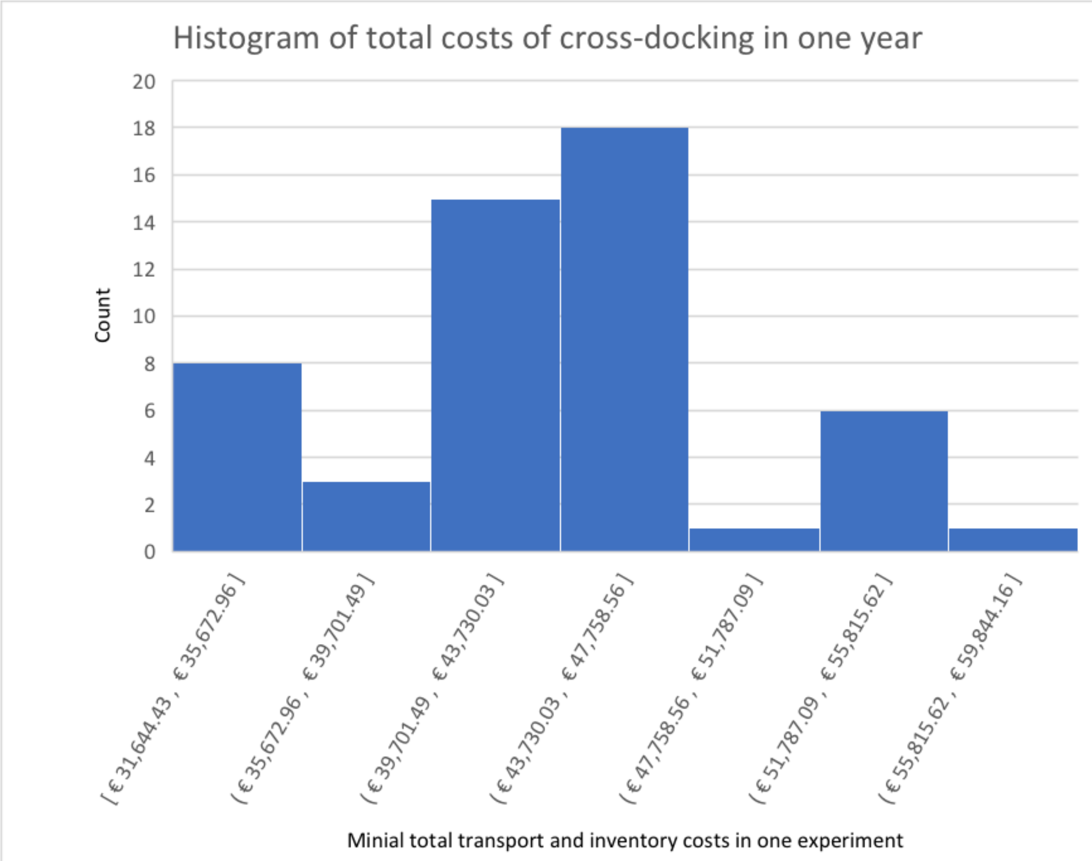


*Figure 5.2 Histogram of one-year weekly total costs by using cross-docking*
Source: Own elaboration

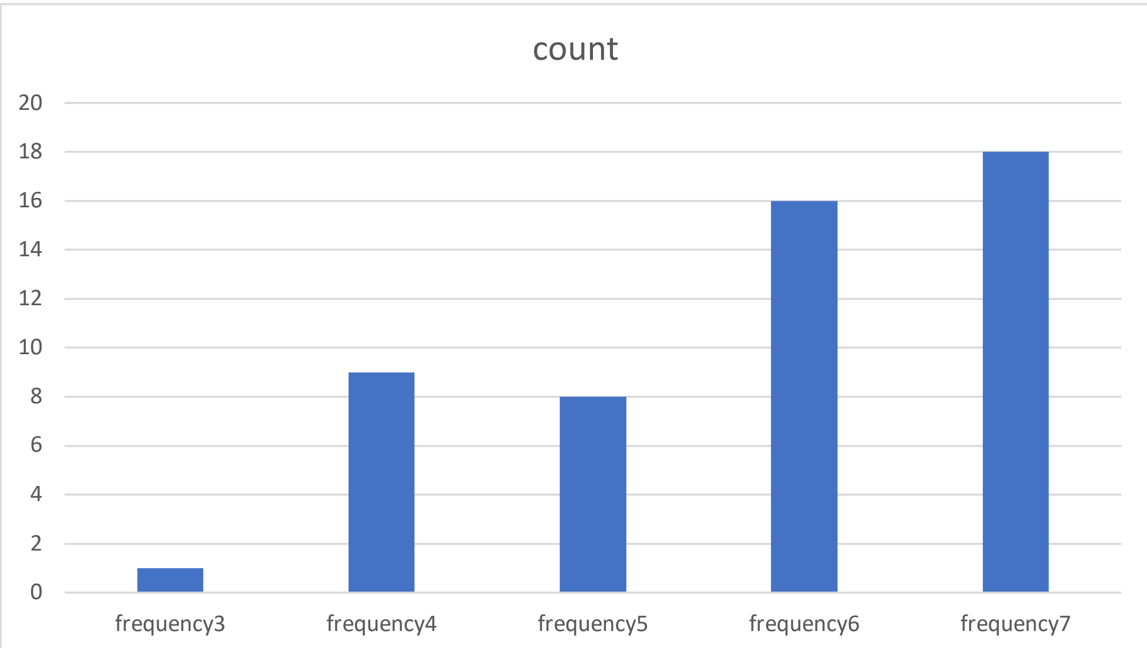


*Figure 5.3 Histogram of one-year optimal delivery frequencies by using cross-docking*
Source: Own elaboration

Figure 5.4 shows the change of average total maritime transport, delivery and inventory costs regarding customer service level and compares the results with weekly maritime transport, delivery and inventory costs when demand is constant.

In overall, cross-docking is more suitable for delivery of bananas from port of Rotterdam to distribution centers of Albert Heijn, because total maritime transport, delivery and inventory costs in cross-docking are much lower than direct shipping. Especially when customer service level increase, the gap between two distribution strategies is much larger. Besides, when demand is uncertain, cross-docking is more flexible than direct shipping. Because of consolidation, optimal delivery frequency would be adjusted by changing demand. The number of reefer containers used, and maritime costs would be lower when demand of bananas is low. Optimal delivery frequencies by using cross-docking are similar with figure 5.3. Most common optimal delivery frequencies are 6 times a week or 7 times a week. However, customer service level does not affect optimal delivery frequency by using direct shipping. No matter in what customer service level, optimal delivery frequencies by using direct shipping are two times a week, because total reefer containers used in a week in that frequency is minimal. Only two reefer containers are needed for each distribution centers in a week.

Furthermore, customer service level has slight impact on total maritime transport, delivery and inventory costs by using cross-docking, compare with by using direct shipping. Customer service level mainly affect order-up-to-level. Since optimal delivery frequency in direct shipping is low, inventory level and inventory costs in direct shipping are vastly high. When order-up-to-level is increased by higher customer service level, inventory costs would largely increase as a result. Therefore, when customer service level improves, total maritime transport, delivery and inventory costs in direct shipping largely increase because of the higher inventory level. In contrast, in most cases of cross-docking optimal delivery frequencies are high and inventory levels in cross-docking are relatively low. So, higher order-up-to-level has slight impact on inventory level and inventory costs of cross-docking. Total maritime transport, delivery and inventory costs are slightly affected by customer service level. Besides, the gap between constant demand and uncertain demand is small by using cross-docking, because of the low inventory level. Therefore, cross-docking is more suitable when demand is uncertain, especially when customer service level is high.

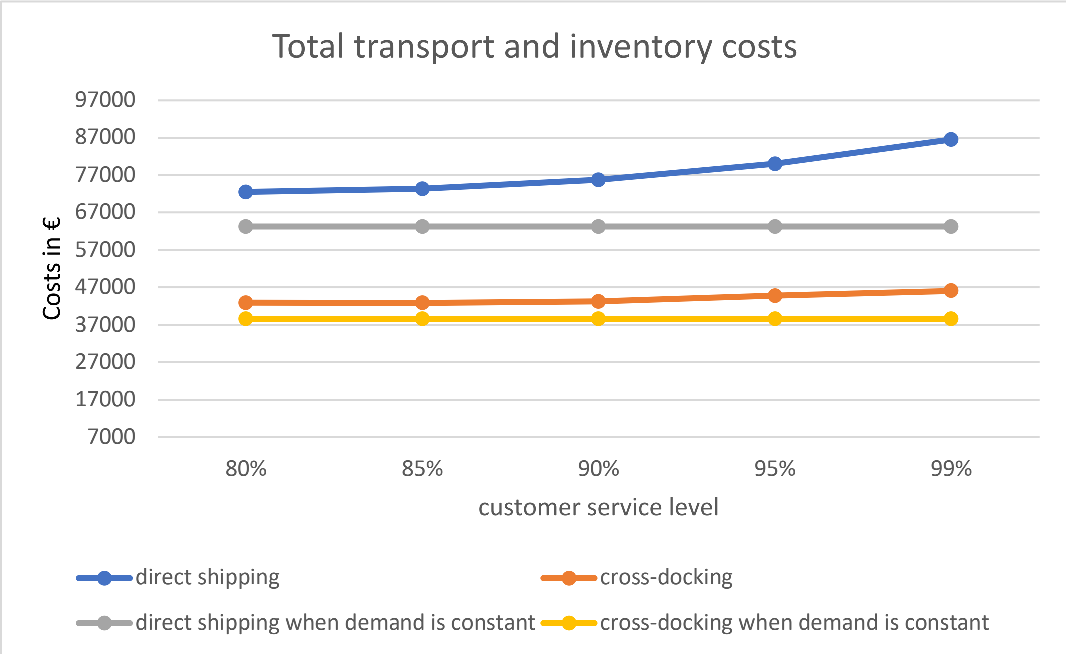


*Figure 5.4 Comparison of two distribution centers in different CSL and in constant demand*
Source: Own elaboration

### *5.3 Sensitivity analyses of demand*

(Berman & Wang, 2006) show that direct shipping is more suitable for products with high demand, especially when the demand of products is large enough to be shipped in full-truck-load (FTL). On the other hand, cross-docking allows product consolidation and increase the utilization of trucks and reduces the transport costs, when demand is low. Besides, (Apte & Viswanathan, 2000) mention that cross-docking is more appropriate for products with relatively stable and constant demand rates. Therefore, in this part we will evaluate the effects of demand rates on the section distribution strategies by sensitive analyzing expected value of demand and standard deviation of demand.

#### *5.3.1 Expected demand $\mu$*

In this part we will illustrate the impact of demand rates on results. We simulate the tests by decreasing and increasing the mean of demand by 30% and 10% respectively. In this part, to calculate order-up-to-level, we use 80% as the customer service level, so that we can compare the results with previous part. Table 5.3 shows the expected demand, standard deviation of demand, and order up to level in variety of delivery frequencies regarding different demand rates.

*Table 5.3 Expected demands, standard deviation of demand, and OUL in different demand rate*

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | frequency | 1.00 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 |
| | duration | 1.00 | 0.50 | 0.33 | 0.25 | 0.20 | 0.17 | 0.14 |
| When demand decrease 30% | expected demand during each period | 21.70 | 10.85 | 7.23 | 5.43 | 4.34 | 3.62 | 3.10 |
| | standard deviation of demand during each period | 11.00 | 7.78 | 6.35 | 5.50 | 4.92 | 4.49 | 4.16 |
| | OUL in each period | 31.00 | 18.00 | 13.00 | 11.00 | 9.00 | 8.00 | 7.00 |
| When demand decrease 10% | expected demand during each period | 27.90 | 13.95 | 9.30 | 6.98 | 5.58 | 4.65 | 3.99 |
| | standard deviation of demand during each period | 11.00 | 7.78 | 6.35 | 5.50 | 4.92 | 4.49 | 4.16 |
| | OUL in each period | 38.00 | 21.00 | 15.00 | 12.00 | 10.00 | 9.00 | 8.00 |
| When demand does not change | expected demand during each period | 31.00 | 15.50 | 10.33 | 7.75 | 6.20 | 5.17 | 4.43 |
| | standard deviation of demand during each period | 11.00 | 7.78 | 6.35 | 5.50 | 4.92 | 4.49 | 4.16 |
| | OUL in each period | 41.00 | 23.00 | 16.00 | 13.00 | 11.00 | 9.00 | 8.00 |
| When demand increase 10% | expected demand during each period | 34.10 | 17.05 | 11.37 | 8.53 | 6.82 | 5.68 | 4.87 |
| | standard deviation of demand during each period | 11.00 | 7.78 | 6.35 | 5.50 | 4.92 | 4.49 | 4.16 |
| | OUL in each period | 44.00 | 24.00 | 17.00 | 14.00 | 11.00 | 10.00 | 9.00 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| When demand increase 30% | expected demand during each period | 40.30 | 20.15 | 13.43 | 10.08 | 8.06 | 6.72 | 5.76 |
| | standard deviation of demand during each period | 11.00 | 7.78 | 6.35 | 5.50 | 4.92 | 4.49 | 4.16 |
| | OUL in each period | 50.00 | 27.00 | 19.00 | 15.00 | 13.00 | 11.00 | 10.00 |

Source: Own elaboration

Figure 5.5 shows how demand rate affects the average weekly transport and inventory costs. It shows that changing expected demand rate within 30% slightly affect weekly maritime transport, delivery and inventory costs by using direct shipping, compares with that using cross-docking. Since demand of bananas is relatively low, increasing demand rate by 30% does not increase the optimal delivery frequency to three times a week by using direct shipping. So, changing demand rate within 30% has no impact on optimal delivery frequency and transport costs of direct shipping. However, changing demand rate would affect the optimal delivery frequency in cross-docking. When demand is low, total number of reefer containers used in one week can be lower. Delivery frequencies in this case are reduced. So, total transport cost including maritime transport and delivery costs are greatly decreased. Although inventory level is increased by lower delivery frequency, lower order-up-to-level could compensate the increased inventory level when demand is low. Besides, decreased transport costs greatly outweigh the increase inventory cost. In contrast, high expected demand would lead to a greater number of reefer containers used and higher maritime transport costs. Especially when demand is extremely high, which excess seven times the reefer container capacity, delivery frequency is lower since more bananas should be shipped in one replenishment cycle. Lower delivery frequency is better for decreasing total reefer containers used in one week. In this case, not only maritime transport costs but also inventory costs increase largely. Therefore, total maritime transport, delivery and inventory costs are extremely affected by expected demand.

By using direct shipping, total maritime transport, delivery and inventory costs are slightly influenced by expected demand rate, because optimal delivery frequencies are not affected by the expected demand. Therefore, total costs are mainly affected by inventory costs, because average inventory costs are increased by higher expected demand. When expected demand increases, order-up-to-level increases as a result. Inventory level at the beginning of replenishment cycle are increased by higher order-up-to-level. Although higher demand would lead to higher consumption in a week, higher consumption could not compensate the increased order-up-to-level. Average inventory level is increased by higher expected demand. However, inventory costs do not capture the mainly percentage of total transport and inventory costs. Expected demand of bananas has slight impact of transport and inventory costs when using direct shipping.

As a result, cross-docking is more suitable when demand rate is low, because total maritime transport, delivery and inventory costs are much lower than direct shipping in low expected demand.

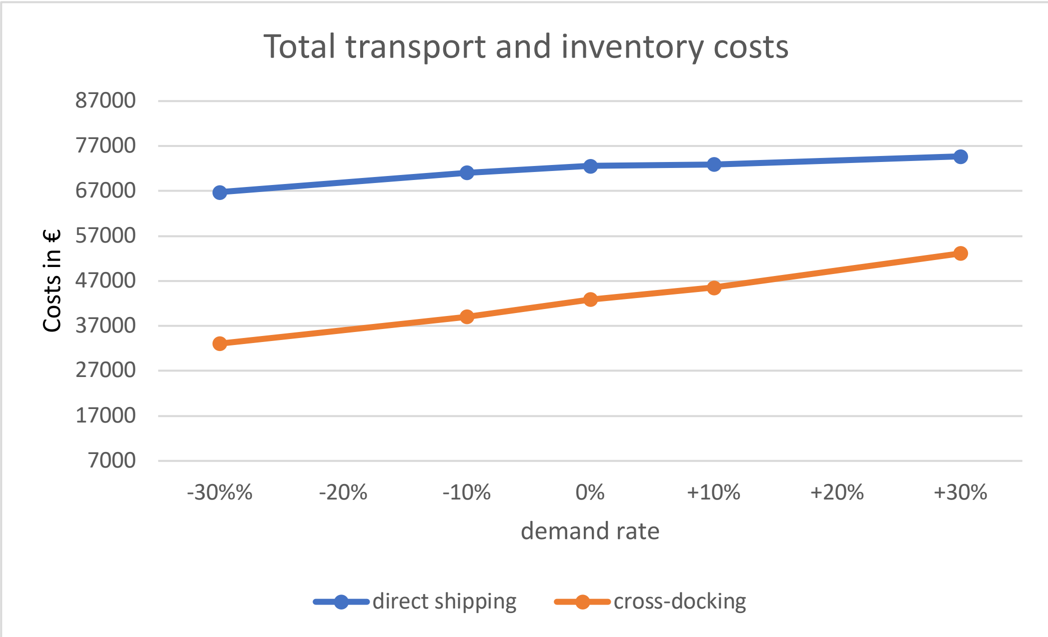


*Figure 5.5 Total maritime transport, delivery and inventory costs in different demand rate*
Source: Own elaboration

### *5.3.2 Standard deviation of demand σ*

In this part we illustrate the impact of standard deviation on results. Standard deviation represents how widely demand distributes over the period. If the standard deviation is small, demand is clustered, that means demand of banana is relatively stable during the period. We simulate the tests by decreasing and increasing the mean of demand by 30% and 10% respectively. Table 5.4 shows the expected demand, standard deviation of demand, and order up to level in variety of delivery frequencies regarding different standard deviation when customer service level is 80%.

*Table 5.4 Expected demand, standard deviation of demand, and OUL in different standard deviation*

| | frequency | 1.00 | 2.00 | 3.00 | 4.00 | 5.00 | 6.00 | 7.00 |
|---|---|---|---|---|---|---|---|---|
| | duration | 1.00 | 0.50 | 0.33 | 0.25 | 0.20 | 0.17 | 0.14 |
| when standard deviation decrease 30% | expected demand during each period | 31.00 | 15.50 | 10.33 | 7.75 | 6.20 | 5.17 | 4.43 |
| | standard deviation of demand during each period | 7.70 | 5.44 | 4.45 | 3.85 | 3.44 | 3.14 | 2.91 |
| | OUL in each period | 38.00 | 21.00 | 15.00 | 11.00 | 10.00 | 8.00 | 7.00 |
| when standard deviation decrease 10% | expected demand during each period | 31.00 | 15.50 | 10.33 | 7.75 | 6.20 | 5.17 | 4.43 |
| | standard deviation of demand during each period | 9.90 | 7.00 | 5.72 | 4.95 | 4.43 | 4.04 | 3.74 |
| | OUL in each period | 40.00 | 22.00 | 16.00 | 12.00 | 10.00 | 9.00 | 8.00 |
| when standard deviation does not change | expected demand during each period | 31.00 | 15.50 | 10.33 | 7.75 | 6.20 | 5.17 | 4.43 |
| | standard deviation of demand during each period | 11.00 | 7.78 | 6.35 | 5.50 | 4.92 | 4.49 | 4.16 |
| | OUL in each period | 41.00 | 23.00 | 16.00 | 13.00 | 11.00 | 9.00 | 8.00 |
| when standard deviation increase 10% | expected demand during each period | 31.00 | 15.50 | 10.33 | 7.75 | 6.20 | 5.17 | 4.43 |
| | standard deviation of demand during each period | 12.10 | 8.56 | 6.99 | 6.05 | 5.41 | 4.94 | 4.57 |
| | OUL in each period | 42.00 | 23.00 | 17.00 | 13.00 | 11.00 | 10.00 | 9.00 |
| when standard deviation increase 30% | expected demand during each period | 31.00 | 15.50 | 10.33 | 7.75 | 6.20 | 5.17 | 4.43 |
| | standard deviation of demand during each period | 14.30 | 10.11 | 8.26 | 7.15 | 6.40 | 5.84 | 5.40 |
| | OUL in each period | 44.00 | 25.00 | 18.00 | 14.00 | 12.00 | 11.00 | 9.00 |

Source: Own elaboration

Figure 5.6 shows that standard deviation has little impact on total maritime transport, delivery and inventory costs for two distribution strategies. Optimal delivery frequency in direct shipping is not affected by changing standard deviation, since expected demand of bananas is low. Only two reefer containers are needed for each distribution centers in a week. Therefore, higher standard deviation only increases the order-up-to-level based on formula (5-1) and bananas consumption in a week. However, widely changing consumption do not affect the average inventory costs and increased order-up-to-level accounts for extremely small proportion of total transport and inventory costs. Therefore, changed standard deviation has slight impact on total maritime transport, delivery and inventory costs of direct shipping. In terms of cross-docking, optimal delivery frequency would be adjusted by different demand rate. As a result, total maritime transport, delivery and inventory costs are relatively constant in different standard deviation of demand. Although increasing standard deviation of demand also increase order-up-to-level, increased inventory costs account for smaller proportion of total costs. Therefore, standard deviation of demand would slightly affect total maritime transport, delivery and inventory costs of two distribution strategies.

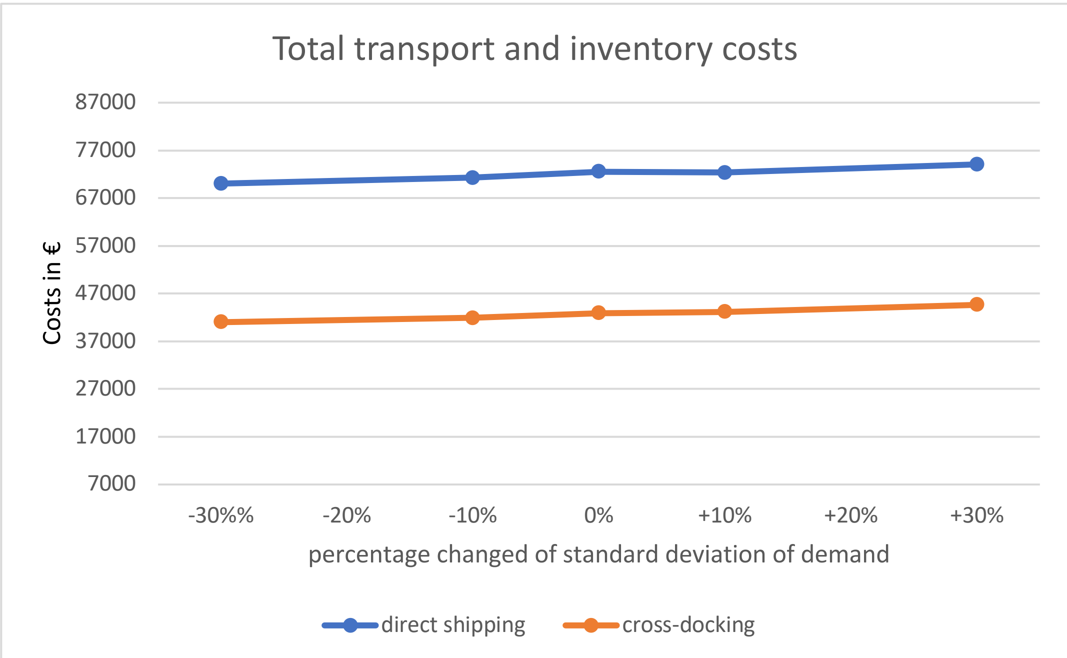


*Figure 5.6 Total maritime transport, delivery and inventory costs in different standard deviation*
Source: Own elaboration

Figure 5.7 shows the standard deviation of total maritime transport, delivery and inventory costs in two distribution strategies. Overall standard deviation of total costs in direct shipping are much lower than that in cross-docking. Since optimal delivery frequencies in direct shipping are regularly two times a week, transport costs do not fluctuate significantly. Increase of standard deviation of demand would increase the fluctuation of the inventory level, so total inventory costs in direct shipping would affected by the increasing standard deviation. Because inventory level in direct shipping is relatively high, increasing standard deviation of demand would enhance the fluctuation of total maritime transport, delivery and inventory costs in direct shipping.

On the other hand, because optimal delivery frequencies are affected by occurred demand, standard deviation of total costs are relatively high in cross-docking. Therefore, when standard deviation of demand enlarges, fluctuation of total costs also increases dramatically. In order to seamless transfer products from inbound trucks to outbound trucks in cross-dock center, movement of products in the cross-dock center should be planned in advance. However, high fluctuation of delivery frequency and total demands would make the planning more complicated. In this case, cross-docking is not so suitable for demand with high standard deviation.

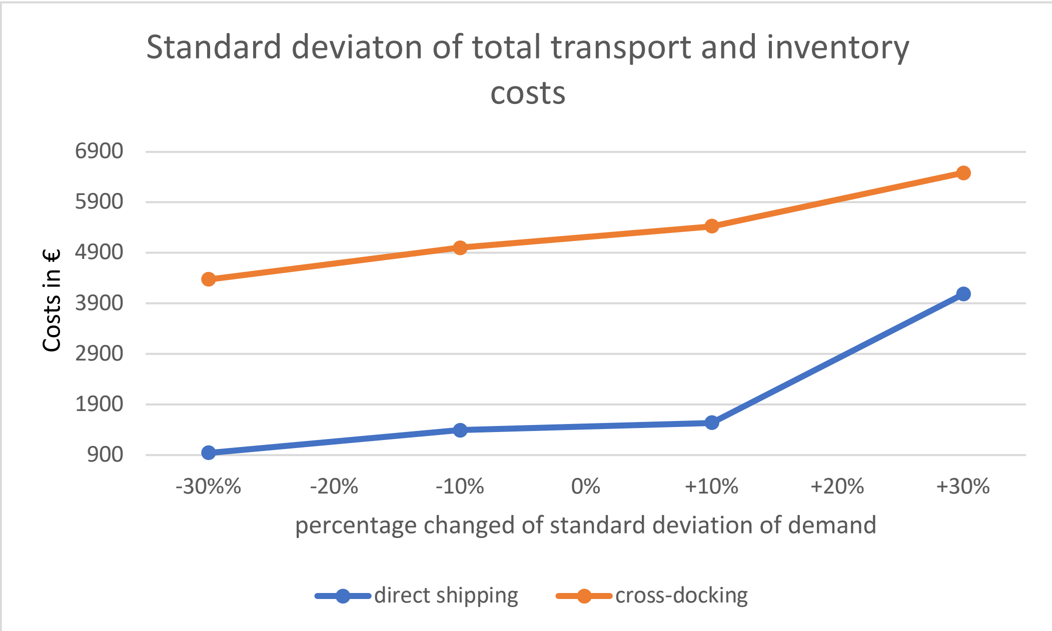


*Figure 5.7 Standard deviation of total costs in different standard deviation of demand*
Source: Own elaboration

### *5.4 Sensitivity analyses of parameters*

Results in section 4 show that maritime transport costs account for largest proportion of total maritime transport, delivery and inventory costs, and then inventory costs capture the second largest proportion. In theory, increasing fixed handling costs would have significantly more impact on the cross-docking than on the direct shipping, because of the additional handling costs in the cross-dock center and high delivery frequencies. Increasing variable transport costs would have significant impact on the direct shipping than in the cross-docking, because variable transport costs rate is lowered by using inland refrigerated trucks. However, since fixed handling costs and variable transport costs capture extremely low proportion of total maritime transport, delivery and inventory costs, changing fixed handling costs rate and variable transport costs rate do not affect the results of two distribution strategies significantly. Figure 5.8 and Figure 5.9 also prove that changing fixed handling costs and variable transport costs slightly affect total maritime transport, delivery and inventory costs in two distribution strategies.

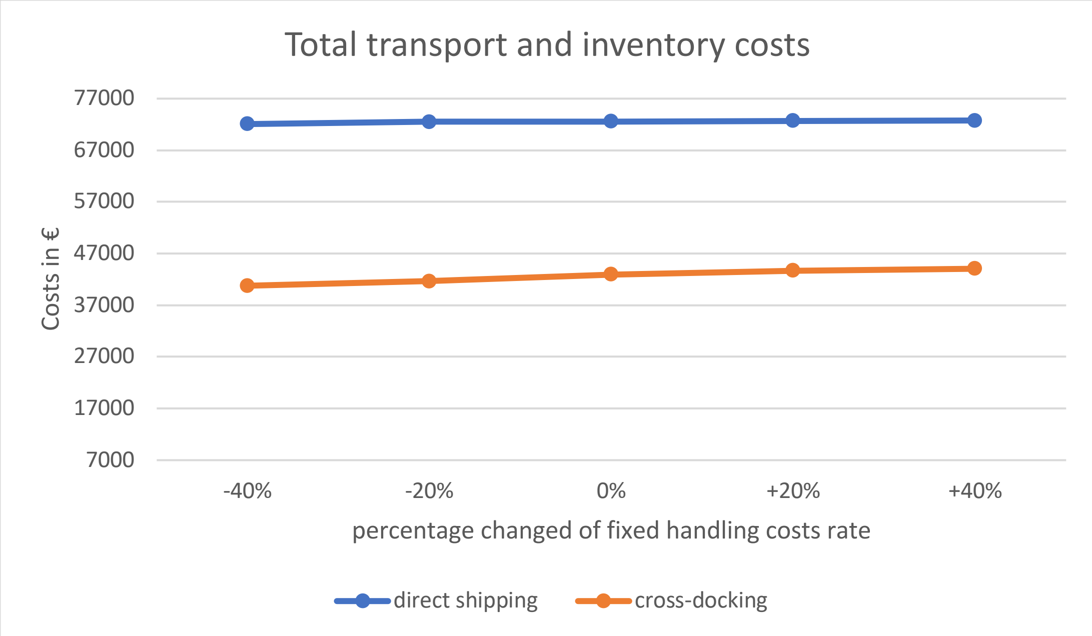


*Figure 5.8 Total maritime transport, delivery and inventory costs in different fixed handling costs rate*
Source: Own elaboration

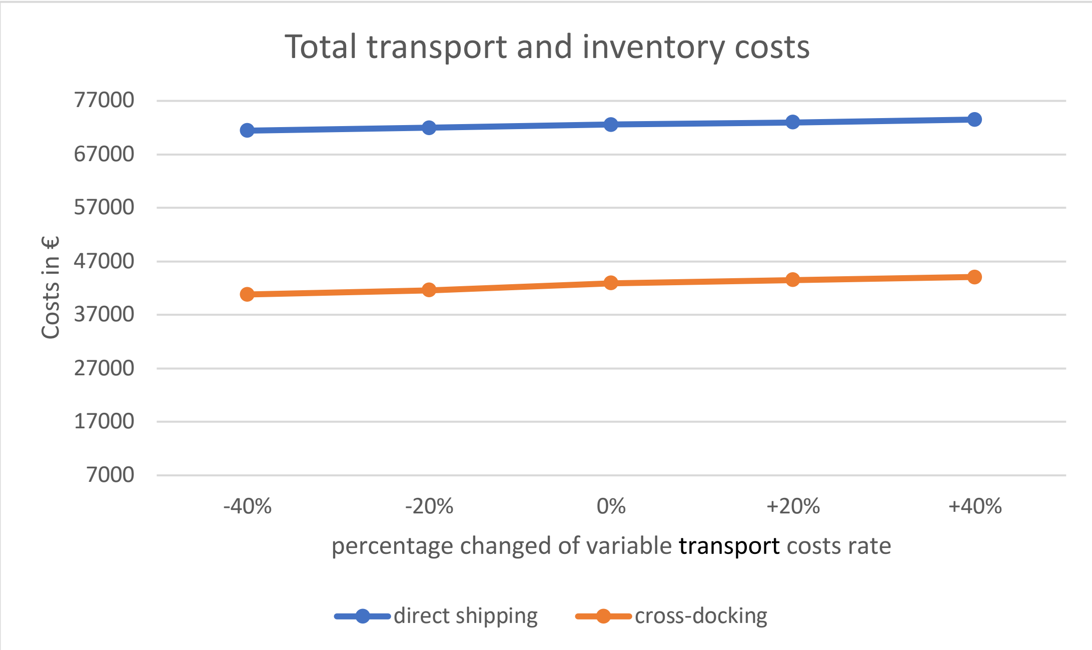


*Figure 5.9 Total maritime transport, delivery and inventory costs in different variable costs rate*
Source: Own elaboration

However, capturing the highest percentage of total maritime transport, delivery and inventory costs, maritime costs rate has significant impact on total costs. Therefore, we conduct sensitive analyses in respect of different maritime transport costs rate. We implement the sensitive analyses when customer service level is 80 % and expected mean and standard deviation of weekly demand are 31 tones and 11 tones, so that we are able to compare the results with section 5.2.

The results are shown in figure 5.10. It shows that optimal delivery frequencies for two distribution strategies are not affected. However, increasing maritime transport costs rate definitely dramatically increase total maritime transport, delivery and inventory costs in two distribution strategies. Since the optimal delivery frequencies by using direct shipping are two times a week, total costs increase by approximate €10,000 when maritime transport costs rate increases by 20%. In respect of cross-docking, total costs are increased relatively slightly, because of the low and flexible optimal delivery frequencies. Total costs increase by approximate €6,000 when maritime transport costs rate increases by 20% by using cross-docking. Therefore, cross-docking is more suitable when maritime transport costs rate is high.

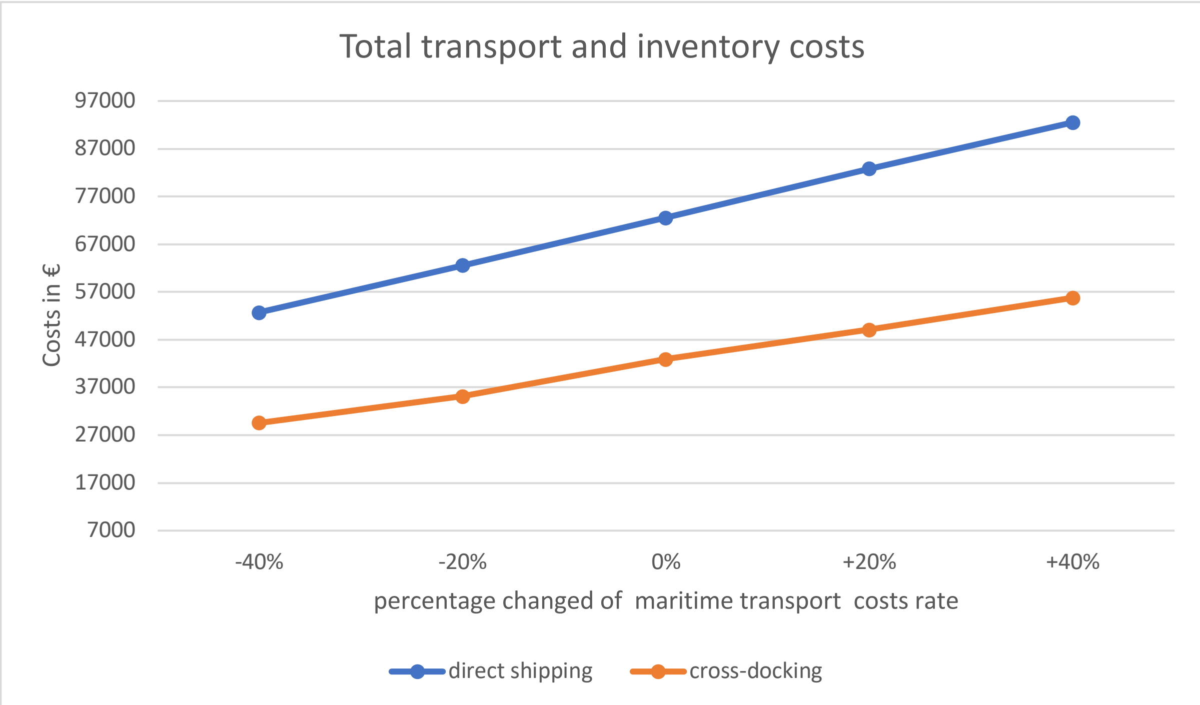


*Figure 5.10 Total maritime transport, delivery and inventory costs in different maritime transport costs rate*
Source: Own elaboration

Furthermore, because of the characteristic of perishable, holding costs of bananas is relatively high. Since inventory costs also capture notable proportion of total transport and inventory costs, in next part we do a sensitive analysis of holding costs rate. We implement the sensitive analysis when customer service level is 80 % and expected mean and standard deviation of weekly demand are 31 tones and 11 tones, so that we are able to compare the results with section 5.2. We use the holding costs rate range mentioned in section 4. Table 5.5 shows the holding costs rate we used in five scenarios.

*Table 5.5 List of holding costs rate in all scenario*

| Holding cost rate (in € per day per ton) | | | | |
|---|---|---|---|---|
| 73.3 | 84.05 | 94.8 | 105.55 | 116.3 |

Source: Own elaboration

Figure 5.11 shows that holding costs rate slightly affect total maritime transport, delivery and inventory costs in cross-docking, compared with that in direct shipping. Since in most of time optimal delivery frequencies in cross-docking are relatively high, inventory levels in cross-docking are low. Increasing holding costs rate does not greatly. increase the inventory costs. However, inventory level in direct shipping is extremely high, due to the low optimal delivery frequency. Therefore, increasing holding costs rate notably increases the inventory costs and enhances the proportion of inventory costs in total costs. As a result, when holding costs rate increase, the gap between two distribution strategies becomes larger. Cross-docking is especially suitable for delivery of products with high holding costs rate.

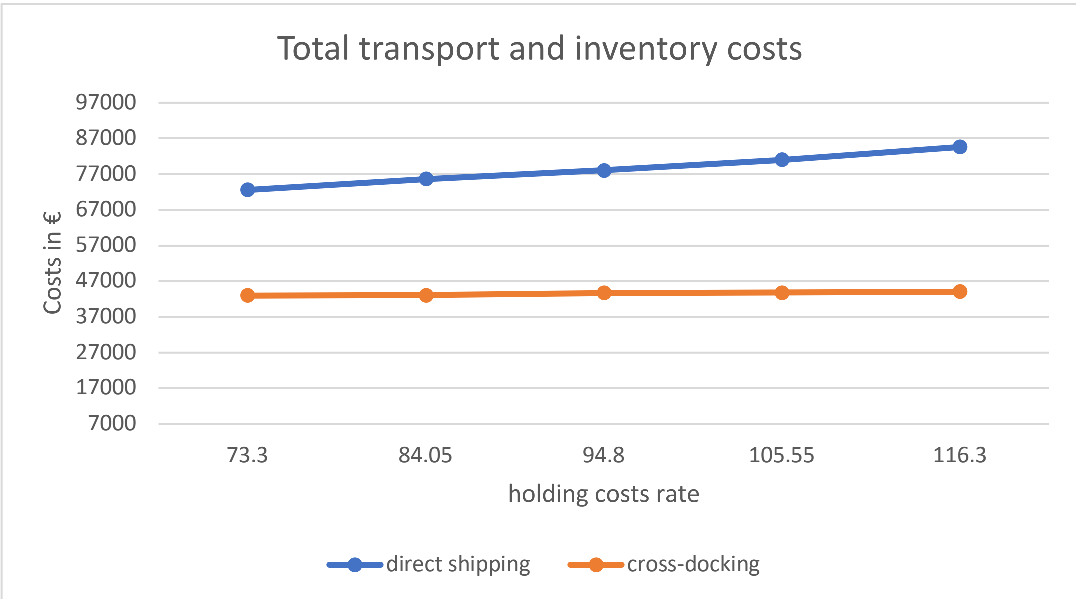


*Figure 5.11 Total maritime transport, delivery and inventory costs in different holding costs rate*

Source: Own elaboration

### *5.5 Discussion*

In this section, we determined the total maritime transport, delivery and inventory costs when demand is uncertain via computation experiments. Overall, total maritime transport, delivery and inventory costs are higher when demand is uncertain, due to the increased inventory level. Optimal delivery frequencies in direct shipping are not affected by changing demand. Optimal delivery frequencies in uncertain demand are the same as the optimal delivery frequency in constant demand, which are two times a week. However, because of consolidation, total number of reefer containers used by using cross-docking is much fewer than that by using direct shipping. Optimal delivery frequencies in cross-docking can be adjusted by changing demand. Besides, uncertain demand largely affects total maritime transport, delivery and inventory costs though inventory level. Because delivery frequencies in cross-docking are mostly higher than in direct shipping, inventory level in cross-docking are mostly lower than in direct shipping. Therefore, by using cross-docking average of weekly costs in uncertain demand and constant demand are similar, compared with that by using direct shipping,

To evaluate the effects of parameters, we also conducted sensitive analysis regarding demand and parameters. In shows that expected mean and standard deviation of weekly demand do not affect optimal delivery frequency in direct shipping but do affect inventory level. Because of  the large capacity of reefer containers and relatively low weekly demand of bananas, changing the demand rate and standard deviation within 30% is not enough to make weekly demand below the reefer containers capacity or above two time of reefer containers capacity. Therefore, optimal delivery frequency is not changed by changing demand rate and standard deviation. Because the demand of bananas are relatively constant, it is not realistic to conduct the sensitive analysis by changing demand rate and standard deviation more than 30%. Further research may test the results with other perishable products, which has larger demand and wider fluctuation.

In terms of cross-docking, because of consolidation, the number of reefer containers used can be easily adjusted by weekly demand. Therefore, optimal delivery frequencies are more flexible. When demand rate is high, more reefer containers are utilised and optimal delivery frequencies are adjusted to delivery more reefer containers in a week. Since maritime transport costs account for largest proportion of total costs, total costs increase dramatically when demand increases. Because of the flexible optimal delivery frequency, total maritime transport, delivery and inventory costs fluctuate greatly among weeks, especially in high standard deviation of demand. However, to achieve seamless transfer products from inbound trucks to outbound trucks, operational network should be planned in advance. When standard deviation of demand is high, advanced planning in the cross-dock center is more complicated. Forecasted data and information regarding demand in distribution centers should be seamlessly passed to the cross-dock center, so that the last-mile delivery can be more smoothly.

Besides, we also conducted sensitivity analyses regarding parameters of fixed handling costs rate, variable transport rates, maritime transport costs rate and holding costs rate. Results show theses parameters do not affect the optimal delivery frequency by using not only cross-docking but also direct shipping. Accounting for low proportion of total costs, fixed handling costs rate and variable transport rate have little effects on total costs in two distribution strategies. However, accounting for the highest proportion of total costs, maritime transport costs dramatically influence the total costs, especially in direct shipping. Besides, since bananas are perishable, inventory costs capture high proportion of total costs in low delivery frequency. Changing holding costs rate notably affects total costs in direct shipping. Because total number of reefer containers used and inventory level in optimal solutions of the cross-docking is much lower than that of direct shipping, cross-docking is more suitable when maritime transport costs rate and holding costs rate are high.

## Chapter 6 Conclusions

In this section we will summarize the findings and highlight the attributions of this thesis. Then we will propose some limitation of this thesis also.

### *6.1 Findings and attributions*

Delivery of perishable products is more complicated than that of other products, because perishable product has limited shelf life time and quality of perishable product is easily degraded. Traditional delivery strategy of perishable product is direct shipping. After being unloading from vessels, containers are delivered from terminals to final destination directly. Due to the high freight rate, the efficient maritime container transport is shipping products in full-truck-load (FTL), resulting low delivery frequency. Cross-docking is an innovative alternative distribution strategy proposed for delivery of perishable product, because product can be consolidated and delivered in high frequency. Motivated by the innovative distribution strategy, we aim to select the optimal distribution strategy for delivery of perishable products.

We proposed integer non-linear programming models to measure total maritime transport, delivery and inventory costs for two distribution strategies. However, non-linear programming models are too complicated to be solved at this stage, so we evaluated the results by simulations. A case study inspired by the delivery of bananas from port of Rotterdam to distribution centers of Albert Heijn was used as an example to solve the simulations. Computational experiments were conducted to analyze the total maritime transport, delivery and inventory costs of the direct shipping and cross-docking when demand is uncertain.

Overall, the cross-docking incurs lower total maritime transport, delivery and inventory costs, compared with the direct shipping in most of the cases. Besides, by using cross-docking delivery frequency can be more flexible and efficiently lowered. The freshness of perishable products can be easily maintained by using cross-docking. Because of high delivery frequency and low inventory level, the cross-docking is especially suitable when customer service level and holding costs rate of the products are high. Furthermore, because of consolidation, the cross-docking notably reduces the number of reefer container used in low demand. Due to the high freight rate, number of reefer containers used largely affects the maritime transport costs, which capture the highest proportion of total transport of inventory costs. Therefore, the cross-docking is also more appropriate in low demand rate and high maritime transport costs rate. However, because of the flexible optimal delivery frequency in cross-docking, advanced planning in the cross-dock center is relatively complicated, especially in widely fluctuated demand. The cross-docking is not so suitable for delivery of products with high standard deviation of demand.

For managerial perspective, the cross-docking provides greatly costs saving in transport and inventory compared with the direct shipping. However, seamlessly transferring products from inbound trucks to outbound trucks requires seamlessly transfer information of demand and vehicles from the distribution centers to the cross-dock center and to the terminal. In this sense, information flows in three facilities are extremely important for smoothly delivery of perishable products.

### *6.2 Limitations*

Firstly transport time is also a determinant for delivery of perishable products, because quality of perishable products would degrade and perishable products would lose their value in the transport. Without consolidation and sorted, transport time in direct shipping is certainly shorter than in cross-dock. Because products are sorted and consolidated in the cross-dock center, service time and planning in the cross-dock center are extremely import for cross-dock. If there are better planning in the cross-dock center, service time and transport time would be shorted. Therefore, further research can include pipeline holding costs into the objective function.

Besides, we only consider delivery of bananas in this case. However, the demand rate of bananas is relatively constant over time. Optimal delivery frequencies in the direct shipping in most of the cases are the same, resulting the same transport costs in direct shipping. Further research can conduct more cases studies regarding different perishable products with different demand rate.

Furthermore, optimal delivery frequencies are largely decided by weekly demand and the restriction of capacity of reefer container. Lower the capacity would result for higher delivery frequencies and maritime transport costs. In this case, the advantage of the cross-docking may loss. Therefore, a sensitive analysis may be conducted in respect of the capacity of reefer containers.

## Reference


Agustina, D., Lee, C. & Piplani, R., (2014). *"Vehicle Scheduling and Routing at a Cross Docking Center for Food Supply Chains"*. International Journal of Production Economics, 152, pp. 29-29.

Ali, M. et al., (2017). "*Food Supply Chain Integrity: The Need to Go Beyond Certification,".* Industrial Management & Data Systems, Volume 117(8), pp. 1589-1611.

Alinaghian, M. & Amanipour, H., (2014). "*Enhancment of Inventory Management Approaches in Vehicle Routing-Cross Docking Problems,".* Journal of Supply Chain Management Systems, Volume 3(3), pp. 27-34.

Apeda.in, (2008). *THE NETHERLANDS - MARKETS FOR FRESH FRUITS AND VEGETABLES.* [Online] Available at: http://apeda.in/agriexchange/Market%20Profile/MOA/CAO/NETHERLANDS.pdf [Accessed Jul. 2018].

Apte, U. & Viswanathan, (2000). "*Effective Cross Docking for Improving Distribution Efficiencies,".* International Journal of Logistics, Volume 3(3), p. 291–302.

Atlas.media.mit.edu, (2018). OEC - Bananas (HS92: 0803) *Product Trade, Exporters and Importers.* [Online] Available at: https://atlas.media.mit.edu/en/profile/hs92/0803/ [Accessed Jul. 2018].

Balaji, M. & Arshinder, K., (2016). "*Modeling the Causes of Food Wastage in Indian Perishable Food Supply Chain,".* Resources, Conservation & Recycling, Volume 114, pp. 153-167.

Berman, O. & Wang, Q., (2006). *"Inbound Logistic Planning: Minimizing Transportation and Inventory Cost,".* Transportation Science,, Volume 40(3), p. 287–299.

Bertazzi, L., Speranza, M. & Ukovich, W., (2000). "*Exact and Heuristic Solutions for a Shipment Problem with Given Frequencies,".* Management Science, Volume 46(7), p. 973–988.

Bortolini, M. et al., (2016). "*Fresh Food Sustainable Distribution: Cost, Delivery Time and Carbon Footprint Three-Objective Optimization,".* Journal of Food Engineering, Volume 174, pp. 56-67.

Bozorgi, A., Pazour, J. & Nazzal, D., (2014). "*A New Inventory Model for Cold Items That Considers Costs and Emissions,".* International Journal of Production Economics, Volume 155, pp. 114-114.

Braekers, K., Ramaekers, K. and Van Nieuwenhuyse, I. (2016) "*The Vehicle Routing Problem: State of the Art Classification and Review,"* Computers & Industrial Engineering, 99, pp. 300–300.

Buijs, P., Danhof, H. & Wortmann, J., (2016). "*Just-In-Time Retail Distribution: A Systems Perspective on Cross-Docking,".* ournal of Business Logistics, Volume 37(3), p. 213–230.
CBS, (2018). *average prices of consumer goods since 2000*. [Online] Available at: https://opendata.cbs.nl/statline/#/CBS/en/dataset/80346eng/table?ts=1532903371978 [Accessed Jul. 2018].

Cbs.nl, 2(017). *Netherlands second largest avocado importer worldwide*. [Online] Available at: https://www.cbs.nl/en-gb/news/2017/19/netherlands-second-largest-avocado-importer-worldwide [Accessed Jul. 2018].

Cbs.nl, (2018). *Dutch agricultural exports at record high.* [Online] Available at: https://www.cbs.nl/en-gb/news/2018/03/dutch-agricultural-exports-at-record-high#id=undefined [Accessed Jul. 2018].

Chen, L. & Notteboom, T., (n.d). *Distribution and value added logistics in the cold chain product market with application to the role of seaports.*

Chopra, S. & Meindl, P., (2013). *MANAGING UNCERTAINTY IN A SUPPLY CHAIN: SAFETY INVENTORY.* In: Supply Chain Management. s.l.:Pearson Education Limited, pp. 326-359.

Coelho, L. & Laporte, G., (2014). "*Optimal Joint Replenishment, Delivery and Inventory Management Policies for Perishable Products,".* Computers & Operations Research, Issue 47, p. 42–42.

Crama, Y., Rezaei, M., Savelsbergh, M. & Woensel, T., (2018). "*Stochastic Inventory Routing for Perishable Products,"*. Transportation Science, Volume 52(3), p. 526–546.

Dekker, N., 2014. Global reefer trades-2014, s.l.: Drewry-maritime research .

Diabat, A., Abdallah, T. & Le, T., (2016). "*A Hybrid Tabu Search Based Heuristic for the Periodic Distribution Inventory Problem with Perishable Goods,".* Annals of Operations Research, Volume 242(2), p. 373–398.

Drewry, (2017). *Market trends and issues for BCOs shipping refrigerated profucts,* s.l.: Drewry.

Enderer, F., Contardo, C. & Contreras, I., (2017). "*Integrating Dock-Door Assignment and Vehicle Routing with Cross-Docking,".* Computers and Operations Research, Volume 88, pp. 30-43.

Fao.org, (2016). *Banana market review*. [Online] Available at: http://www.fao.org/3/a-i7410e.pdf [Accessed Jul. 2018].

Fauza, G., Amer, Y., Lee, S.-H. & Prasetyo, H., (2016). "*An Integrated Single-Vendor Multi-Buyer Production-Inventory Policy for Food Products Incorporating Quality Degradation,"*. International Journal of Production Economics, Volume 182, p. 409–409.

Federgruen, A., Prastacos, G. & Zipkin PH , P., (1986). *"An allocation and distribution model for perishable products".* Operations Research , 34(1), pp. 75-82.

Hsiao, Y.-H., Chen, M.-C. & Chin, C.-L., (2017). “*Distribution planning for perishable foods in cold chains with quality concerns: Formulation and solution procedure.”* Trends in Food Science & Technology, pp. 80-93.

Hsu, C.-I., Chen, W.-T. & Wu, W.-J., (2013). “*Optimal Delivery Cycles for Joint Distribution of Multi-Temperature Food,”.* Food control, Volume 34(1), p. 106–114.

Hu, W., Toriello, A. & Dessouky, M., (2018). *“Integrated Inventory Routing and Freight Consolidationfor Perishable Goods,”.* European Journal of Operational Research.

Ladier, A.-L. & Gülgün , A., (2016). “*Cross-Docking Operations: Current Research Versus Industry Practice,”*. Omega, Volume 62, pp. 145-145.

Liao, C.-J., Lin, Y. & Shih, . S. C., (2010). “*Vehicle Routing with Cross-Docking in the Supply Chain,”.* Expert Systems With Applications, Volume 37(10), p. 6868–6873.

Logistiek, (2018). Logistiek.nl. [Online] Available at: https://www.logistiek.nl/carriere-mensen/nieuws/2017/07/distributiecentrum-albert-heijn-blijft-doelwit-acties-101157194 [Accessed Jul. 2018].

Maknoon, M., Soumis, F. & Baptiste, P., (2016). *“Optimizing Transshipment Workloads in Less-Than-Truckload Cross-Docks,”.* International Journal of Production Economics, Volume 179, pp. 90-90.

Maknoon, Y. & Laporte, G., (2017). *“Vehicle Routing with Cross-Dock Selection,”.* Computers & Operations Research, Volume 77, p. 254–254.

Malladi, K. & Sowlati, T., (2018). “*Sustainability Aspects in Inventory Routing Problem: A Review of New Trends in the Literature,”*. Journal of Cleaner Production, Volume 197, pp. 804-814.

Nguyen, C., Dessouky, M. & Toriello, A., (2014). “*Consolidation Strategies for the Delivery of Perishable Products,”.* Transportation Research. Part E, Logistics & Transportation Review, Volume 69, pp. 108-108.

Nikolopoulou, A., Repoussis, P. P. P., Tarantilis, C. & Zachariadis, E., (2014). “*Moving Products between Location Pairs: Cross-Docking Versus Direct-Shipping,”.* European Journal of Operational Research, Volume 256(3), pp. 803-803.

Osvald, A. and Stirn, L. Z. (2098). *“A Vehicle Routing Algorithm for the Distribution of Fresh Vegetables and Similar Perishable Food,”* Journal of Food Engineering, 85(2), pp. 285–295. doi: 10.1016/j.jfoodeng.2007.07.008.

Oxfamnovib.nl, (2018). *dutch supermarket supply chains.* [Online] Available at: https://www.oxfamnovib.nl/Files/rapporten/2018/20180621%20Oxfam%20Behind%20the%20Barcodes_Dutch%20supermarket%20supply%20chains.pdf [Accessed Jul. 2018].

Port of Rotterdam, (2018). *Rotterdam as your cool port.* [Online] Available at: https://www.portofrotterdam.com/nl/file/1524/download?token=1_vvonnv [Accessed July 2018].

Raak, N. et al., (2017). *" Processing- and product-related causes for food waste and implications for the food supply chain".* Waste Management, Volume 61, pp. 461-472.

Rong, A., Akkerman, R. & Grunow, M., (2011). *"An optimization approach for managing fresh food quality throughout the supply chain".* International Journal of Production Economics, 131(1), pp. 421-429.

Serrano, C., Moral, J., Delorme, X. & Dolgui, A., (2016). "*Cross-Docking Operation Scheduling: Truck Arrivals, Shop-Floor Activities and Truck Departures,".* IFAC PapersOnLine, Volume 49(12), pp. 1353-1358.

Seyedhosseini, S. & Ghoreyshi, S., (2014). "*An Integrated Model for Production and Distribution Planning of Perishable Products with Inventory and Routing Considerations ".* Mathematical Problems in Engineering.

Shukla, M. & Jharkharia, S., (2013). "*Agri-Fresh Produce Supply Chain Management : A State-Of-The-Art Literature Review,".* International journal of operations & production management, Volume 33(2), p. 114–158.

Soysal, M., Bloemhof-Ruwaard, J. M. & Bektaş, T., (2015). "*The time-dependent two-echelon capacitated vehicle routing problem with environmental considerations."* Production Economics, p. 366–378.

Statista, (2018). *Netherlands: Albert Heijn market share in supermarket retail 2012-2016* | Statistic. [Online] Available at: https://www.statista.com/statistics/729905/albert-heijn-market-share-in-supermarket-retail-in-the-netherlands/ [Accessed Jul. 2018].

Statista, (2018). *Netherlands: value import and export bananas 2008-2016* | Statistic. [Online] Available at: https://www.statista.com/statistics/571279/value-of-the-import-and-export-of-bananas-in-the-netherlands/ [Accessed Jul. 2018].

Van Belle, J., Valckenaers, P. & Cattrysse, D., (2012). "*Cross-Docking: State of the Art,".* Omega, Volume 40(6), pp. 827-827.

Wen, M. et al., (2009). "*Vehicle Routing with Cross-Docking,".* The Journal of the Operational Research Society, 60(12)(1708–1718).

Worldfreightrates, (2018). *World Freight Rates - Freight Calculator*. [Online] Available at: http://worldfreightrates.com/freight1 [Accessed Jul. 2018].

Yu, M. & Nagurney, A., (2013). "*Competitive Food Supply Chain Networks with Application to Fresh Produce,".* European Journal of Operational Research, Volume 224(2), pp. 273-273.

## Appendices

Appendix A: Detailed results by using direct shipping when customer service level is 80%

| Experiment No. | Minimal total costs (€) | Optimal delivery frequency (times per week) | Average demand of five distribution centers (tons) |
|---|---|---|---|
| 1 | 74,206 | 2 | 26 |
| 2 | 72,282 | 2 | 32 |
| 3 | 72,731 | 2 | 30.6 |
| 4 | 77,733 | 2 | 15 |
| 5 | 74,719 | 2 | 24.4 |
| 6 | 70,999 | 2 | 36 |
| 7 | 74,078 | 2 | 26.4 |
| 8 | 74,078 | 2 | 26.4 |
| 9 | 72,987 | 2 | 30.4 |
| 10 | 72,025 | 2 | 32.8 |
| 11 | 71,127 | 2 | 35.6 |
| 12 | 71,384 | 2 | 34.8 |
| 13 | 71,897 | 2 | 33.2 |
| 14 | 71,961 | 2 | 33 |
| 15 | 71,191 | 2 | 36 |
| 16 | 73,244 | 2 | 29 |
| 17 | 72,795 | 2 | 30.4 |
| 18 | 72,089 | 2 | 37.4 |
| 19 | 74,270 | 2 | 25.8 |
| 20 | 71,897 | 2 | 37 |
| 21 | 72,538 | 2 | 31.4 |
| 22 | 73,564 | 2 | 29.8 |
| 23 | 71,897 | 2 | 35.8 |
| 24 | 72,474 | 2 | 31.4 |
| 25 | 76,194 | 2 | 19.8 |
| 26 | 72,346 | 2 | 31.8 |
| 27 | 73,500 | 2 | 29.4 |
| 28 | 72,025 | 2 | 35.6 |
| 29 | 72,731 | 2 | 30.6 |
| 30 | 73,500 | 2 | 28.2 |
| 31 | 72,795 | 2 | 32.4 |
| 32 | 72,602 | 2 | 31.2 |
| 33 | 70,935 | 2 | 36.2 |

| | | | |
|---|---|---|---|
| 34 | 71,640 | 2 | 37.8 |
| 35 | 73,115 | 2 | 29.4 |
| 36 | 71,704 | 2 | 34.4 |
| 37 | 70,871 | 2 | 39 |
| 38 | 71,127 | 2 | 35.8 |
| 39 | 71,191 | 2 | 35.6 |
| 40 | 72,282 | 2 | 32 |
| 41 | 74,013 | 2 | 26.6 |
| 42 | 75,553 | 2 | 21.8 |
| 43 | 73,821 | 2 | 27.2 |
| 44 | 69,909 | 2 | 40.2 |
| 45 | 70,486 | 2 | 37.6 |
| 46 | 70,358 | 2 | 40.4 |
| 47 | 73,436 | 2 | 28.4 |
| 48 | 72,410 | 2 | 32.4 |
| 49 | 72,538 | 2 | 31.2 |
| 50 | 70,293 | 2 | 39.4 |
| 51 | 72,025 | 2 | 34.8 |
| 52 | 71,448 | 2 | 34.6 |

Appendix B: Detailed outcomes by using cross-docking when customer service level is 80%

| Experiment No. | Minimal total costs (€) | Optimal delivery frequency (times per week) | Average demand of five distribution centers (tons) | Total number of reefer containers should be used in one week |
|---|---|---|---|---|
| 1 | 45,712 | 7 | 36.4 | 7 |
| 2 | 40,208 | 6 | 31.6 | 6 |
| 3 | 40,279 | 6 | 29.6 | 6 |
| 4 | 35,732 | 5 | 22.4 | 5 |
| 5 | 52,317 | 4 | 38.6 | 8 |
| 6 | 35,763 | 5 | 21.8 | 5 |
| 7 | 45,749 | 7 | 35 | 7 |
| 8 | 40,300 | 6 | 29 | 6 |
| 9 | 35,609 | 5 | 24.8 | 5 |
| 10 | 40,300 | 6 | 29 | 6 |
| 11 | 53,153 | 4 | 38.8 | 8 |
| 12 | 45,728 | 7 | 35.8 | 7 |
| 13 | 40,329 | 6 | 28.2 | 6 |
| 14 | 35,589 | 5 | 25.2 | 5 |
| 15 | 40,364 | 6 | 27.2 | 6 |
| 16 | 45,811 | 7 | 32.6 | 7 |
| 17 | 40,222 | 6 | 31.2 | 6 |
| 18 | 35,548 | 5 | 26 | 5 |
| 19 | 45,775 | 7 | 34 | 7 |
| 20 | 45,722 | 7 | 36 | 7 |
| 21 | 45,790 | 7 | 33.4 | 7 |

| | | | | |
|---|---|---|---|---|
| 22 | 31,709 | 4 | 20.2 | 4 |
| 23 | 45,801 | 7 | 33 | 7 |
| 24 | 40,222 | 6 | 31.2 | 6 |
| 25 | 40,314 | 6 | 28.6 | 6 |
| 26 | 59,844 | 3 | 43.4 | 9 |
| 27 | 45,759 | 7 | 34.6 | 7 |
| 28 | 40,314 | 6 | 28.6 | 6 |
| 29 | 35,558 | 5 | 25.8 | 5 |
| 30 | 38,933 | 6 | 29.6 | 6 |
| 31 | 45,686 | 7 | 37.4 | 7 |
| 32 | 45,717 | 7 | 36.2 | 7 |
| 33 | 35,517 | 5 | 26.6 | 5 |
| 34 | 45,749 | 7 | 35 | 7 |
| 35 | 31,644 | 4 | 21 | 4 |
| 36 | 45,749 | 7 | 35 | 7 |
| 37 | 40,293 | 6 | 29.2 | 6 |
| 38 | 40,229 | 6 | 31 | 6 |
| 39 | 45,790 | 7 | 33.4 | 7 |
| 40 | 52,156 | 4 | 40.2 | 8 |
| 41 | 52,315 | 4 | 42 | 8 |
| 42 | 45,785 | 7 | 33.6 | 7 |
| 43 | 52,799 | 4 | 41.4 | 8 |
| 44 | 53,036 | 4 | 38.8 | 8 |
| 45 | 35,517 | 5 | 26.6 | 5 |
| 46 | 40,314 | 6 | 28.6 | 6 |

| | | | | |
|---|---|---|---|---|
| 47 | 45,717 | 7 | 36.2 | 7 |
| 48 | 45,775 | 7 | 34 | 7 |
| 49 | 51,368 | 4 | 39.6 | 8 |
| 50 | 45,775 | 7 | 34 | 7 |
| 51 | 40,229 | 6 | 31 | 6 |
| 52 | 40,229 | 6 | 31 | 6 |