

MASTER

Strategic distribution flow type selection for perishables

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Veghel, September 2015

**Strategic distribution flow type selection for
perishables**

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in partial fulfilment of the requirements for the degree of

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in Operations Management and Logistics

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ABSTRACT

This report describes the design of a distribution flow type selection model for supply chains in grocery retailing, specifically aiming at perishables. The MILP-model includes handling and transportation costs at both retailer and supplier and selects the optimal flow type for each supplier. Results show that 'stockless for supplier'-flow types outperform other flow types under most circumstances. Furthermore, this study proposes a hybrid cross-docking flow type, which is cost efficient for a smaller set of suppliers. Pick-to-zero and put-to-zero operations are outperformed by either the 'stockless for supplier'-flow types or the hybrid cross-docking flow type. In addition, the model can be adjusted for different distribution networks and shows how optimal flow types differ when the distribution network changes. Thereby it facilitates distribution flow type selection on a tactical and strategic level as well as better strategic decision making on network designs.

MANAGEMENT SUMMARY

Like many retailers, Jumbo is constantly trying to improve the performance of its supply chain to meet increasing consumer demands. The every-day-low-price formula requires an every-day-low-cost supply chain. Strategic supply chain planning can help to achieve this. One of the strategic supply chain planning problems is the distribution flow type selection. It includes the determination and (re)design of the physical distribution structures between sources (i.e. suppliers) and customers (i.e. retail outlets). It creates structures for transportation modes, such as warehouse delivery or cross-dock delivery.

In this master thesis we identify and analyze distribution flow types for the temperature-controlled supply chain of Jumbo. Thereby we answer the following research question:

What are the best distribution flow types for fresh products in a retail supply chain such that overall costs are lowest, while maintaining or improving freshness at the outlet with a predefined service level?

Distribution flow types

The conceptual model is presented in the following figure. The left column is called primary distribution and deals with the logistics of the supplier. The middle column, secondary distribution, deals with the logistics of the retailer on national level, meaning that the retailer may use a national distribution center (NDC). The right column is called tertiary distribution. It is the final stage before the goods are received at the outlet. Similar to secondary distribution, tertiary distribution can either skip the regional distribution centers (option '0'), apply a stockless solution (option '1'), or keep stock at the RDCs (option '2').

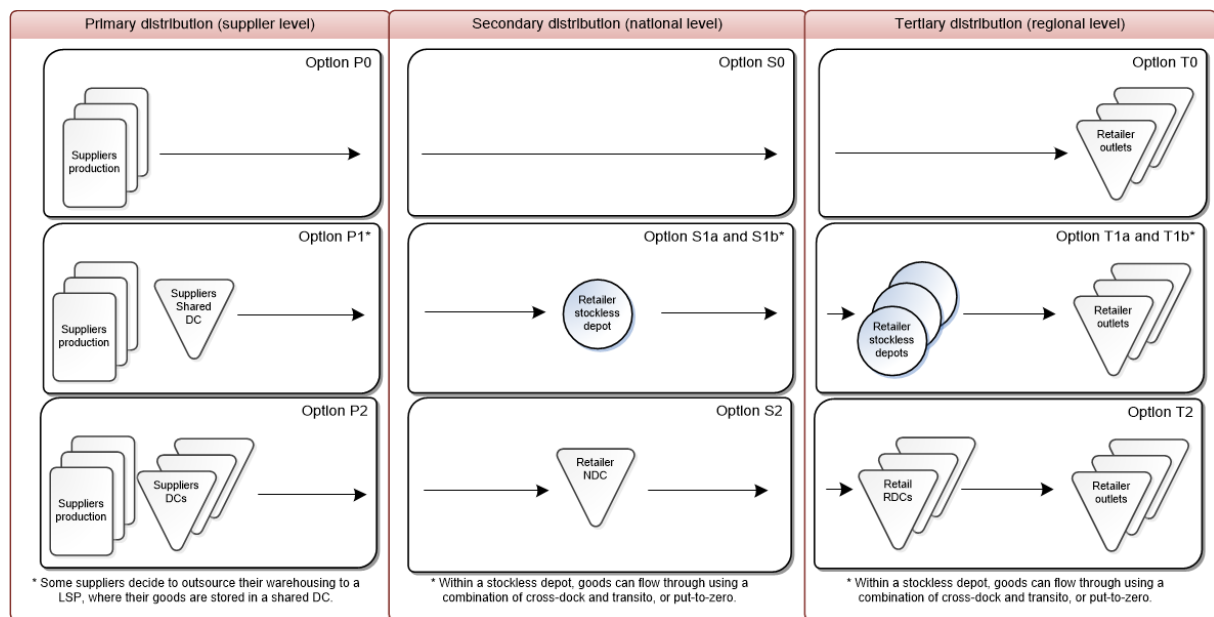


Figure 0.1: Distribution flow types

When combining blocks from primary, secondary and tertiary distribution, one can build a distribution flow type. Theoretically there are many flow types to be identified. However, most flow types are considered impossible or undesirable due to the functional requirements in terms of costs, freshness and service level. In order to improve freshness and service levels while reducing costs, it is argued that a supply chain should have exactly one inventory point. Compared to the traditional supply chains with inventory at both supplier and retailer, one inventory point should be eliminated in order to improve supply chain performance. Then, the flow types can be roughly classified into 'stockless for supplier'-flow types and 'stockless for retailer'-flow types. Two examples are given in the figure below. The first flow type (2-1-0) is an example of a 'stockless for retailer'-flow type, as the retailer does not hold inventory, but the

NDC only functions as a consolidation point. The second is a ‘stockless for supplier’-flow type (0-2-1), where the retailer keeps inventory at the NDC and consolidates shipments at the RDCs.

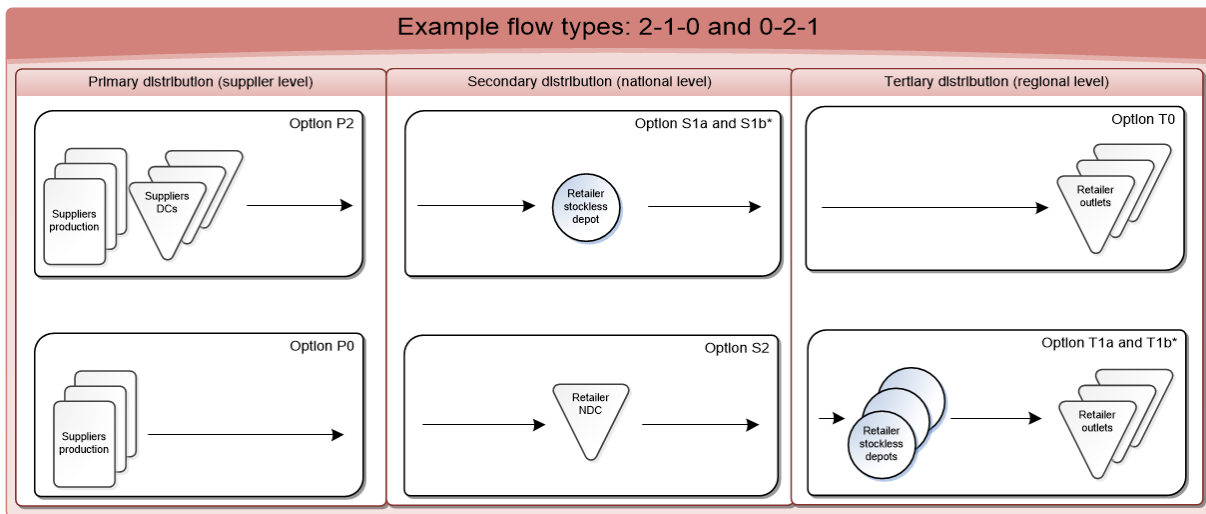


Figure 0.2: Example flow types

Stockless for retailer flow types

Within the ‘stockless for retailer’-flow types a number of variants can be identified. Jumbo uses the following definitions: cross-dock (XD) means that the supplier picks at outlet level and sends outlet-specific carriers to the stockless depot. Transito (TR) is similar in that the supplier picks at outlet level, but now in outlet-specific boxes. At the stockless depot the carriers and boxes for a specific outlet are combined with carriers and boxes from other suppliers and are sent to the outlet. In this study, we suggest to apply a hybrid form of cross-dock and transito (XD-TR), where cross-dock and transito can be used simultaneously on a daily basis. A supplier combines orders on outlet level and stacks them on a carrier. When the volume per outlet is high, there is no need to stack multiple outlets on one carrier to save on transportation costs (transito) and to keep outlets on a separate carrier is less costly (cross-dock). At the retailer DC, both cross-dock and transito carriers will arrive. By using a simple identification trigger, for instance a colored sticker, the employees at the retailer DC can immediately see the difference and split the two streams. Put-to-zero (PTZ) is a flow type in which the supplier picks an order for the total aggregate outlet demand. This pallet is sent to the stockless depot, where the pallet moves from outlet to outlet on a floor containing all outlets. When an outlet needs this product, it is picked from this moving pallet. At the final outlet, the pallet is empty (hence the term put-to-zero). Pick-to-zero is a similar alternative where pallets have a fixed location and carriers of outlets move from pallet to pallet, thereby having the same physical lay-out as traditional stock-keeping.

Stockless for supplier flow types

Another way to eliminate an inventory point in the supply chain is to ship products to retail distribution centers immediately after production. These flow types are suggested by Van der Vlist (2007), which he called Supply Chain Synchronization.

Relevant costs

The objective is to minimize the total supply chain-wide costs. An initial analysis reveals that for the temperature-controlled assortment the main cost drivers are currently handling, transport and waste (Figure 0.3). The quantitative model is therefore based on handling and transport costs. Waste costs are excluded from the quantitative analysis because it is shown that the cost difference among the relevant flow types is small. Perishables are relatively fast-moving and are replenished frequently, such that the imbalance problem is limited. The imbalance problem requires more safety stock when inventory is kept downstream in the supply chain.

Current retailer supply chain costs

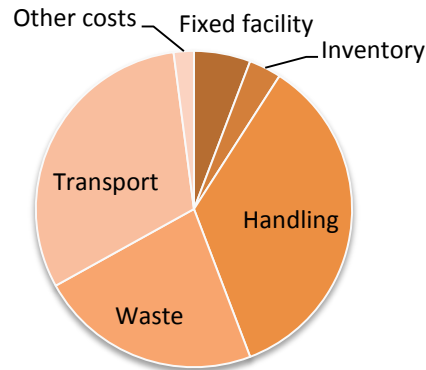


Figure 0.3: Current retailer supply chain cost breakdown (supplier not included)

Results

Three flow types were identified as most interesting. These are ‘stockless for supplier’-flow types 0-2-1a and 0-0-2, and ‘stockless for retailer’-flow type 2-0-1a. In case of the former two, the suppliers deliver immediately after production to the NDC (0-2-1a) or to the RDCs (0-0-2). For most suppliers flow type 0-0-2 (inventory at RDCs) is the best flow type in terms of total supply chain costs. Suppliers with slow moving fresh should deliver at the NDC. For fresh products the delivery frequency (or number of batches per week) should be high in order to prevent waste. This, in combination with low sales volumes make it very expensive to split the delivery over multiple RDCs. Hence, delivering at the NDC is better. Regarding the ‘stockless for retailer’-flow types, XD-TR at the RDC (2-0-1a) performs well. Especially for suppliers that usually have either many items, multiple case packs per box, big boxes, medium to high sales volumes, or a combination of these characteristics. Also, there are possibilities to further improve this by increasing the box sizes and by placing multiple case packs (SKUs) in a box. Furthermore, this study has concluded that a pick/put-to-zero-operation is not cost efficient at the RDCs due to the high number of pallets that need to be handled. Pick-to-zero might only be interesting when using a single NDC, but the cost savings compared to excluding pick-to-zero are very small. Besides, these cost savings arise under tricky assumptions. For instance, the assumption that no storing activities will take place while for high volumes this is rather unrealistic.

Network

Next to the optimal flow type selection of suppliers, this study also investigates the effect of future distribution network changes on the optimal flow type selection. Five network structures were evaluated. The results show that optimal flow type selection depends on the distribution network. For instance, when having only one NDC it is cheapest to apply the ‘stockless for supplier’-flow type (0-2-0) for almost all suppliers.

Having only three RDCs is the cheapest in terms of handling and transport. Furthermore, it is more realistic than having only one NDC. Besides, this scenario allows to go to this situation gradually by going from a scenario with four RDCs and a NDC, to a scenario with three RDCs and a NDC, to a scenario with only three RDCs. These insights facilitate better strategic decision making on network designs.

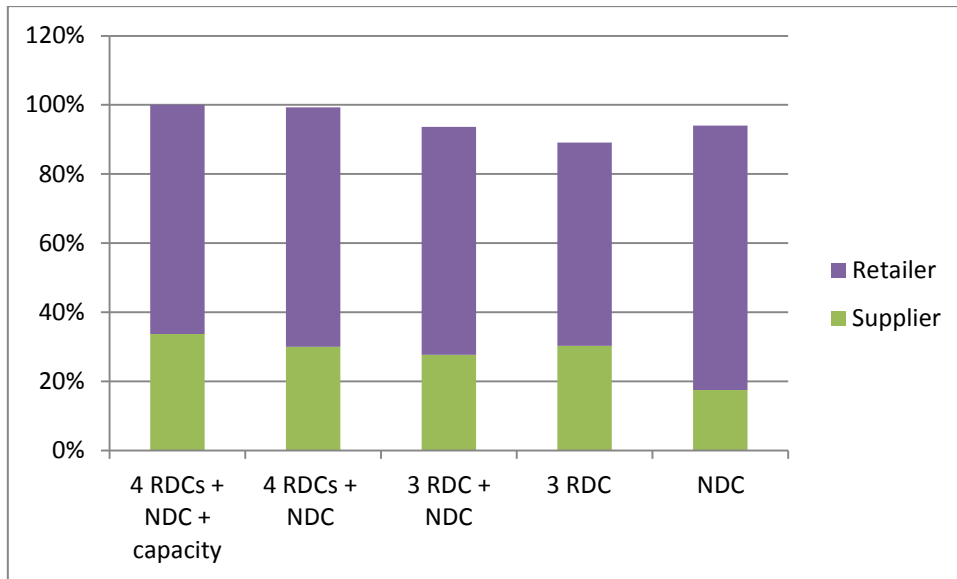


Figure 0.4: Total costs split over supplier and retailer for each scenario

Recommendations for Jumbo

- Focus on implementing 'stockless for supplier'-flow types in collaboration with suppliers. These flow types are generally most cost efficient. Besides, they are quite similar to the traditional flow types with two inventory points.
- Facilitate a XD-TR flow type at the RDCs (i.e. 2-0-1a). Cost savings can be expected immediately for the current transit suppliers. This will also allow possible growth in assortment (number of SKUs) as costs do not depend on the number of SKUs for this flow type.
- Do not implement a put-to-zero operation. For most suppliers this is not cost efficient and it will not be worthwhile to implement such an operation. On the other hand, pick-to-zero might be interesting for some suppliers or SKUs. As flow types 0-2-0 and 0-0-2 have a quite similar process as flow types 2-1b-0 and 2-0-1b (pick-to-zero), Jumbo might consider to use them simultaneously for some suppliers.
- Separate logistics costs from purchase price. By doing so, more knowledge can be obtained about the supplier costs. This knowledge can also be used to make a better consideration on where activities should take place, or for instance to find opportunities for backhauling.
- When changing the distribution network, keep in mind that optimal flow types change. This model can be used to show the effects in terms of handling and transportation costs. Furthermore, this study shows that a network with three RDCs is most cost efficient for supply chain-wide transportation and handling costs. It is also recommended to investigate the possibilities for a carousel, where assortment-specific RDCs are used as NDCs. This decreases the costs for suppliers, although inter-DC transportation costs increase. Appendix E provides additional information on this topic.

PREFACE

This report is the product of my master thesis project, which I conducted at Jumbo Supermarkten in Veghel. It is the final report that I will hand in to fulfil my master degree in Operations Management & Logistics at Eindhoven University of Technology. It is also the end of my life as a student, which has been a great time. I would like to express my gratitude to the people who have made this a very pleasant and instructive period of my life.

First of all, my thanks go out to my supervisors Karel van Donselaar and Rob Broekmeulen. During the course 'Retail Operations' you were able to show what a great sector retail is. This has inspired me to continue working in this field. I am very thankful for the guidance during my master thesis and I am honored to have discussed a number of retail topics with experts in the field.

Next, I would like to thank Jumbo and all project managers of Supply Chain Development for giving me the opportunity to write my thesis at this very dynamic company. In particular, I would like to thank Marion van der Spek. Marion, thank you for your guidance and feedback. I found our meetings always very inspirational, especially the ones where we discussed future scenarios. I appreciate your constant drive to improve supply chains and ability to think outside the box. I would also like to thank Jaap de Hoop as initiator of this project for giving me the resources I needed to conduct this research. Furthermore, thanks to Mark van Helvoort and Maurice Gerts for providing a lot of information and data, but also for the discussions that helped me to improve my model.

Furthermore, I would like to thank my fellow students and friends for making this a wonderful period of my life. We have had great times both inside and outside university and I really enjoyed the fun we had. In particular the participants of the International Research Project 2014. The study tour to the United States of America has been an amazing experience and is something I will never forget.

Finally, I want to thank my friends and family. Especially my parents, who deserve most credits. There has not been one moment in my life where I did not feel your unconditional support. I am very grateful for that. And last, but certainly not least, thanks to Thérèse. The past two years, your support has been very encouraging and I look forward to sharing our future.

LIST OF ABBREVIATIONS

CODP	Customer Order Decoupling Point
DC	Distribution Center
DSCP	Demand and Supply Chain Planning
FTL	Full Truckload
LSP	Logistics Service Provider
LTL	Less than Truckload
MTC	Multi-Temperature-Controlled trailer
NDC	National Distribution Center
PTZ	Put/Pick-To-Zero
RDC	Regional Distribution Center
SCS	Supply Chain Synchronization
STC	Single-Temperature-Controlled trailer
TR	Transito
VMI	Vendor Managed Inventory
XD	Cross-docking
XD-TR	Cross-dock/transito combination

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1 INTRODUCTION

This chapter functions as an introduction to this master thesis. It consists of an introduction to the company and the problem context. Finally, the report outline will be discussed.

1.1 PROBLEM CONTEXT

Many retailers find that their distribution network is one of their core competences. It is of critical importance in the retail industry, since it can provide competitive advantage in a highly competitive market. The supply chain for groceries consists of several stages. More specifically, one could say that the total supply chain of for instance cheese consists of all parties from cow to customer (Harrison & Van Hoek, 2011). For the example of cheese, the material flows from a dairy cooperative via a cheese factory, a supplier distribution center (DC) and a retailer DC to the retailer outlet and end-customer. So the retail supply chain is typically modelled from supplier or manufacturer to consumer. However, in this report the viewpoint of the retailer is taken and it is assumed that the supply chain starts at the manufacturing plant and ends at the retail outlet. Van der Vlist (2007) used the same definition and depicted the retail supply chain in Figure 1.1. As can be seen in this figure, he distinguishes between primary (from manufacturer to retailer DC) and secondary (from retailer DC to outlets) distribution. This report will use a multi-stage approach, in which both distribution movements will be taken into account. The report will only consider the chilled supply chain, so frozen and ambient supply chains are excluded.

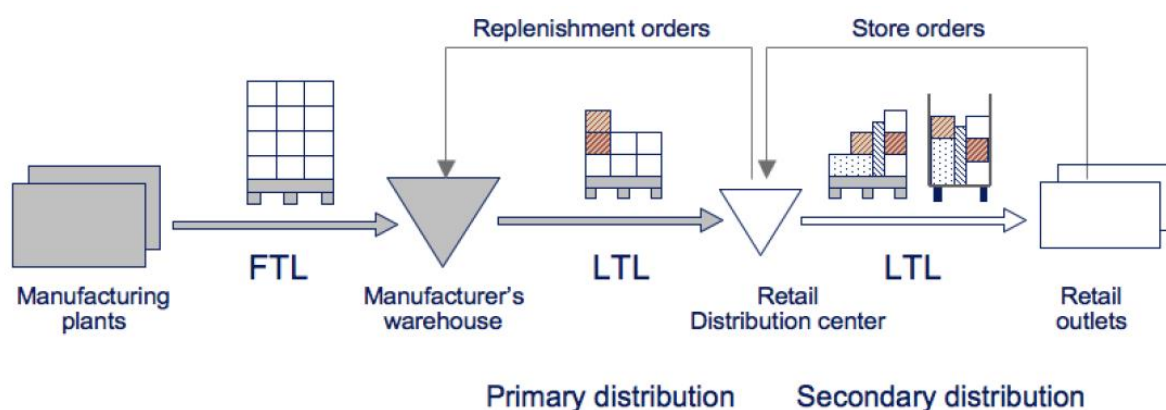


Figure 1.1: supply chain network (Van der Vlist, 2007)

1.2 JUMBO

Jumbo Supermarkten is a family-owned company that was founded in 1921. It started as a wholesaler, experimented with different supermarket concepts and started with Jumbo in the late 1970s. Jumbo is a fast-growing grocery retailer based in the Netherlands. The company has grown very fast in the past decade because of the acquisition of Super de Boer in 2009 and C1000 in 2012. After the integration of C1000 it has 579 outlets, which makes it the second largest supermarket retailer in the Netherlands with a market share of approximately 20%. The core values of Jumbo are embedded in the seven guarantees ("7 Zekerheden"), by which they aim to provide low prices, high service, broad assortment (more than 32.000 items) and fresh products to consumers. This is very challenging because some of the guarantees are contradictory (such as low price and high service). Furthermore, the company not only has supermarkets, it also has food markets at which fresh food is prepared that can be consumed on the premises. Next to that, the company has an e-commerce department that allows consumers to order online and pick-up their orders at pick-up points or at outlets. (Jumbo Supermarkten, 2015).

1.2.1 CURRENT SUPPLY CHAIN

Delivering products as fresh as possible to the outlets, food markets and e-commerce at acceptable costs and service levels requires a lot from the supply chain. The distribution of goods is done in three temperature zones: frozen, chilled and ambient. For most fresh products chilled storage and transportation is required. By chilled we mean at 2-4⁰ Celsius. However, there are also products that require a temperature of 13⁰ Celsius, such as bananas. For these, mostly agricultural products, a separate storage and picking area is used. For transportation of chilled products the temperature is set at 2-4⁰ Celsius and the moderate temperature agricultural products are transported in the same trailer with a slipcover so that these products keep a higher temperature during transportation. Another option is to transport these goods in multi-temperature trailers, where not only 2-4⁰ Celsius and 13⁰ Celsius are combined, but also includes the possibility to ship ambient products in a single trailer. Jumbo currently has many of these multi-temperature trailers, as a heritage of the acquisition of C1000.

Because of the acquisition of Super de Boer and C1000, the company has many distribution centers (DCs). The chilled supply chain has one national distribution center (NDC) in Veghel and four regional distribution centers (RDCs) in Veghel, Breda, Woerden and Beilen. The NDC is used for storing and picking slow-moving fresh products that are then delivered to the RDCs which contain fast-moving fresh products. The products are combined at the RDCs, from where they are transported to the outlets. The RDCs also receive pre-order picked cross-dock carriers from external suppliers. The goods are delivered on outlet-level, so at the RDC they only need to move the carrier from one truck into another, including some additional activities such as labelling and sometimes stacking.

1.3 REPORT STRUCTURE

This chapter has introduced the problem context and the company. In the next chapter, a more elaborate discussion is given about the problem and its scope and motivation. The chapter also includes the research questions and methodology. Chapter three contains a literature review and benchmark analysis in order to investigate what has been done on this topic both in research and practice. Chapter four describes the conceptual model. It forms a framework for the supply chain design, which is then quantified in chapter 5. The quantitative model includes the mathematical formulation of the model. In chapter 6 the model is solved and the chapter provides insights in current and future supply chain designs. Chapter 7 provides information on how the solution could be implemented for Jumbo in practice. Finally, chapter 8 concludes this master thesis and provides recommendations for Jumbo and for future research.

2 PROBLEM DESCRIPTION

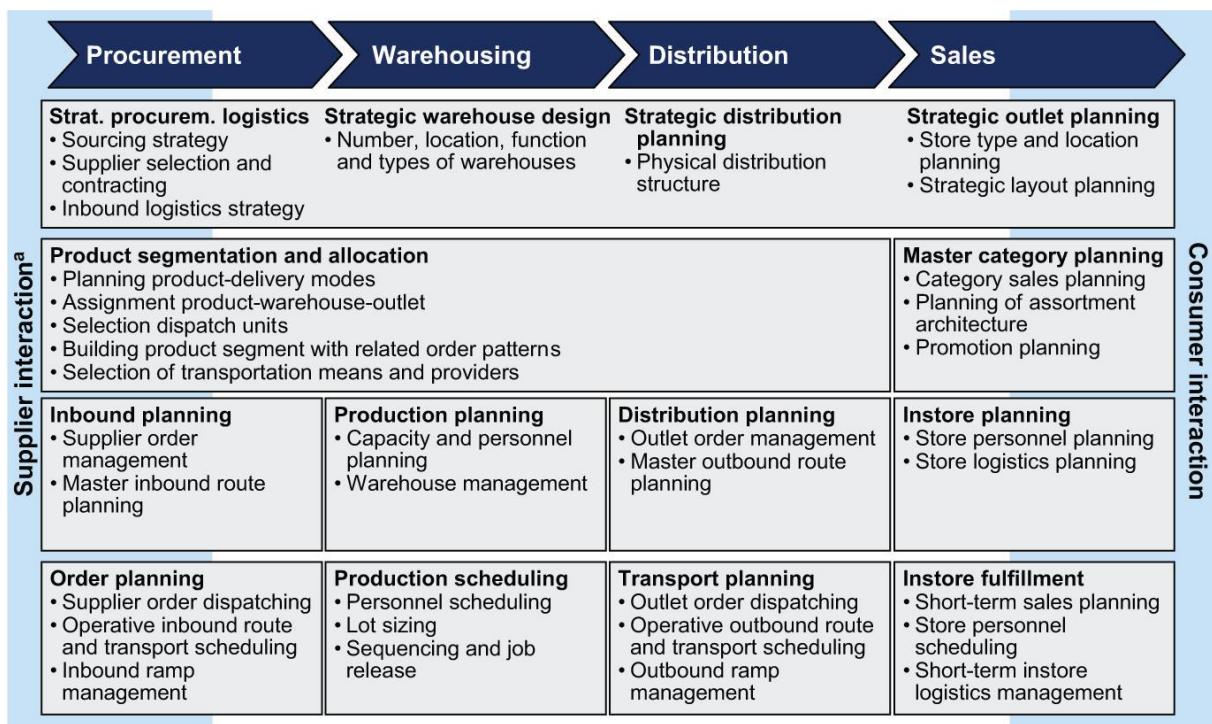
This chapter describes the problem and delineates the scope of this master thesis. Important aspects of what exactly is studied will be clarified. This includes the type of problem and its interrelationship with other sub problems, but also the delineation of the assortment. This chapter concludes with the research questions and methodology.

2.1 PROBLEM SCOPE

Before developing a model, the scope of the project should be defined and supported. In this section it is argued what choices will be made and how the model will be built. This includes a number of assumptions that will delineate the scope.

2.1.1 RESEARCH MOTIVATION

The supply chain should be designed in such a way that it supports the seven guarantees that are promised to customers at the retail outlets. This means that the supply chain should be able to deliver the right quantities, at the right place at the right moment in time, at the best level of quality at the lowest cost. Therefore Jumbo is developing a distribution vision for 2025 in which the supply chain should be able to perform better in terms of costs, service level and freshness of products. Especially the latter is interesting for the perishables supply chain. One of Jumbo's guarantees to customers is that fresh should be really fresh. Therefore, for some perishables it is very important that they flow as fast as possible through the supply chain. For other products this might be less of an issue or actually need to ripen for some time such that faster is not always better. This master thesis will be part of the project that develops that vision.



Note: ^aincluding supplier-relationship management and collaboration

Figure 2.1: Demand and supply chain planning framework (Hübner et al., 2013)

2.1.2 CLASSIFICATION OF DEMAND AND SUPPLY CHAIN PLANNING PROBLEMS

Design problems are complex. One approach to deal with this complexity is to decompose the problem into sub-problems, such that each of these problems can be solved independently, keeping in mind their interdependence. The decomposition should be done such that the sub-problems are weakly dependent. Hübner et al. (2013) developed a coherent demand and supply

chain planning (DSCP) framework for retail operations (Figure 2.1). According to the authors the retail industry is different from the manufacturing industry in that retailers typically have a higher share of distribution costs. Also, they deal with products of relatively low value. The primary objective of retailers is to bridge the gap between the point of production and the point of sales, on which the framework is based. On the vertical axis the framework distinguishes between long-term (strategic), mid-term (tactical) and short-term (operational) planning. On the horizontal axis the framework is embedded between consumer interaction downstream and supplier interaction upstream. The matrix provides a comprehensive guide for retailers DSCP problems and serves for the classification of planning problems.

2.1.3 SEQUENCE OF DECISION MAKING

The sequence in which the demand and supply chain planning problems are solved can serve as a guide to design a supply chain. Now that the design problem has been decomposed into several sub-problems, it is important to determine their interdependencies and the sequence in which they can be solved. Hübner et al. (2013) are not clear in what sequence the problems should be solved. However, their framework in Figure 2.1 provides a good overview of what decisions should be taken and the sequence in which they should be taken can be derived from it. Designing a supply chain is foremost a strategic issue, restricting sub-problems to the upper part of the framework.

- At the top left, *strategic procurement logistics* includes supplier relationship management and collaboration. It includes the decisions on segment-specific sourcing modes, supplier selection and contracting, and inbound logistics strategy. Especially the latter is interesting from a supply chain perspective. It covers long-term aspects of the inbound logistics, how goods flow from supplier to retailer, and regulates responsibilities.
- *Strategic warehouse design* (i.e. strategic network design) governs the number, location, function and types of warehouses. It requires a trade-off decision between transportation, inventory and fixed site costs. The function of warehouses deals with the decision of whether to use central and/or regional warehouses. The type of warehouse determines whether a facility stores or handles frozen, chilled or ambient products.
- *Strategic distribution planning* (i.e. distribution flow type selection) includes the determination and (re)design of the physical distribution structures between sources (e.g. suppliers) and customers (e.g. retail outlets). It *creates structures for transportation modes*, such as direct delivery, warehouse delivery or cross-dock delivery. In this master thesis the structures will be called distribution flow types.
- *Strategic outlet planning* deals with the selection of outlet types (formats) and locations.

As most decisions are interdependent, it not trivial in what sequence they have to be taken. Figure 2.2 shows the most realistic sequence, which will be explained in the next section from the viewpoint of distribution flow type selection.

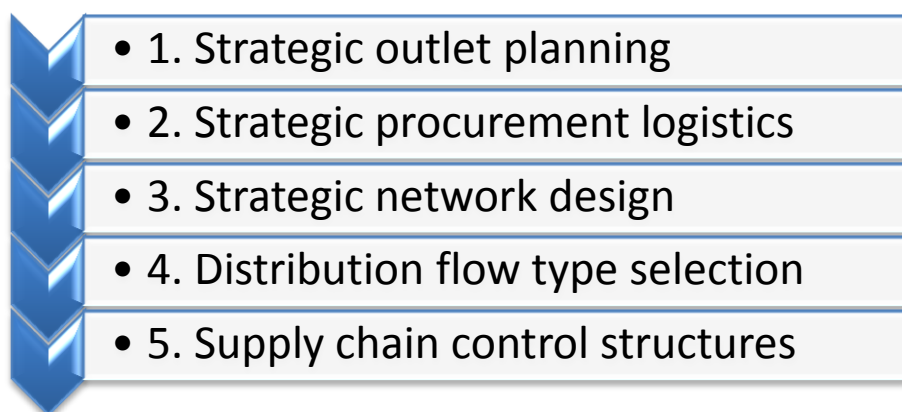


Figure 2.2: Sequence of decision making in strategic supply chain design

2.1.4 DISTRIBUTION FLOW TYPE SELECTION

This research will mainly deal with distribution flow type selection. The term distribution flow type is introduced, which is derived from Van den Heijkant (2006). A flow type is a way that goods flow from supplier to outlets. Hübner et al. (2013) describe this term as strategic distribution planning.

Jumbo currently has three formats: Jumbo supermarkets, Jumbo food markets and Jumbo e-commerce. According to Jumbo, the selection of formats and locations of outlets is a commercial decision. The supply chain should adapt to the decisions made here. Therefore, these type of strategic decisions are taken before all others. This research includes all Jumbo outlets, assuming they will have comparable turnover as they have now and will be located at their current location. Furthermore, Jumbo food market and Jumbo e-commerce are left out of scope. At this point these streams are quite small and are not expected to influence the final decisions on flow type selection.

The relationship with the supplier decides what distribution flow types are possible. When the retailer decides to function as a stockless depot, it is more difficult to switch from supplier. The retailer becomes more dependent on this supplier, which might be an undesirable situation from a sourcing perspective. This means that the possible distribution flow types are dependent on the procurement strategy, because they can be restricted by it. Strategic procurement logistics requires a long-term vision from the procurement department, deciding on whether or not strategic partnerships will be engaged in. It is assumed that there are no restrictions on flow types due to supplier restrictions. However, the model will be built in such a way that flow types can easily be included and excluded for each supplier.

It is assumed that strategic network design decisions have already been made. However, in reality this is not yet the case. The facility location-allocation problem is considered out of scope, because this will be covered in another sub-project which will determine the number and locations of facilities. Note that when determining a flow type, it effects the number, function and type of facilities in the network. Or, when determining the strategic network design, it will limit the options for the distribution flow type selection. For instance, when it is decided to only have a single central warehouse, cross-docking cannot take place at a regional warehouse, because there are no regional warehouses. Once a strategic network design is chosen, the possible distribution flow types can be identified and the best one can be selected.

2.1.5 SUPPLY CHAIN CONTROL STRUCTURES

The supply chain control structures are tactical decisions that are taken after the distribution flow type selection. Many of the mid-term master planning level decisions (Hübner et al., 2013) are tactical control issues and will therefore be called supply chain control structures. This includes assigning products to warehouses, selecting packaging units, building product segments, selecting transportation means, deciding on order quantities, warehouse layout planning, deciding on delivery frequencies etcetera. Many of these decisions will not be dealt with in this research, such as warehouse layout planning. However, some of the issues are needed to perform calculations for the distribution flow type selection, such as deciding on delivery frequencies. These will be regarded as input parameters, based on the current settings within Jumbo. The most important of these tactical decisions are discussed here.

The customer order decoupling point (CODP) is an important supply chain control mechanism. For the consumer, the CODP is in the store. However, how the store inventory is replenished depends on the distribution flow type that is selected. The CODP for the store is implicitly decided when choosing a distribution flow type. Starting at the store inventory, it is the first inventory point when moving upstream in the supply chain. For instance, when a product is cross-docked at the retailer and supplied from the supplier's DC, the CODP is at the supplier's DC.

The lead times between different points in the supply chain (e.g. between retailer DC and retailer store) is dependent on the flow type and on the location of both points. The time between a store order and delivery should be at most 24 hours, which is the current situation.

At Jumbo, the order and delivery schedules are fixed, such that replenishment policies are based on periodic review. These order and delivery schedules are determined for each store and its assortment, which is decided based on the volume, perishability and on shelf space availability. Delivery frequency has an effect on several costs and service performance measures, such as handling and transportation costs and service level at the store. However, the optimization of the delivery frequencies is out of scope for this research. Instead, this research uses delivery frequency as an input parameter for the model, using the current order and delivery schedules as a base.

The minimum order size and case pack size are also considered as input parameters for the model, for which also the current settings at Jumbo will be used as a base.

2.1.6 DELINEATION OF ASSORTMENT

For this master thesis project, not all product flows will be investigated. Two factors are important for selecting the distribution flow types: temperature and perishability. Jumbo roughly has three temperature zones: ambient, chilled and frozen. The internal definition for 'fresh' products comprises of all products that are stored and transported through the chilled supply chain. This research will focus on the chilled supply chain and will not include ambient and frozen products. These are considered as non-perishables, although bread and newspapers are also characterized by having a very short shelf life. However, as they do not require a temperature-controlled environment, they will not be included in this research. On the other hand, there are products that require a temperature-controlled environment, but cannot be classified as perishables, as their shelf life is relatively high (e.g. margarine and sauerkraut). These products will be included, as they are stored and transported together with perishable products and will influence for instance the utilization of trucks. So delineating the assortment is done by the following definition: all products that require a temperature-controlled environment with a temperature of above 0⁰ Celsius.

The term 'temperature-controlled' requires additional explanation. Within the chilled temperature zone, Jumbo distinguishes between 13⁰ and 2⁰ Celsius. In their warehouses two separate storage areas are used that are connected to each other by an automatic door. When cooling the warehouse or trailers, the minimum temperature of the air that flows out of the cooling unit is set such that the products will not suffer from any cold. For transportation, the two streams are combined. This is done either in a multi-temperature-controlled (MTC) trailer or with the use of slipcovers in single-temperature-controlled (STC) trailers. In this way, fewer drops will take place at the outlets and a higher utilization of the trailer is achieved. MTC trailers are also used to combine ambient with fresh assortment. At present it is unclear whether in the future the slipcovers, the MTC trailers or both will be used. Another possibility would be to split the streams, but this option is regarded as undesirable as the goal will be to minimize the number of drops at outlets and to maximize the utilization of trailers. Both options are considered as sufficient in terms of quality (temperature is stable in both options for the duration of 24 hours), so the main difference between slipcovers and MTC trailers will be related to costs. MTC trailers are more expensive in purchase and maintenance compared to STC trailers. Also, splitting the loading space in the trailer will decrease the capacity of the trailer. Capacity and utilization will likely be lower for a second reason as well, as these trailers are unable to transport pallets. This might make logistic service providers (LSPs) reluctant to invest in these type of trailers. On the other hand, slipcovers also require an investment. Moreover, the use of slipcovers will require extra handling. What exactly is a better option is a different study and is left out of scope in this research. Both slipcovers and MTC trailers have their advantages and disadvantages. For the calculations in this research we will assume that STC trailers in combination with slipcovers will be used.

2.2 RESEARCH QUESTION

The research question is derived from the problem description as described in the previous section. Also, the motivation for this research is key in determining the research question. In this case it is about designing the best supply chain and since it is not obvious how this should be done, the research question is stated as follows:

What are the best distribution flow types for fresh products in a retail supply chain such that overall costs are lowest, while maintaining or improving freshness at the outlet with a predefined service level?

In order to answer this question, we have derived and formulated a number of sub-questions:

1. Based on product and supplier characteristics, what relevant product classes can be identified?
2. What relevant distribution flow types can be identified?
3. What modelling approach to evaluate relevant supply chain scenarios is appropriate?
4. What are the relevant performance measures in terms of costs and service and how can they be evaluated?
5. What are the advantages and disadvantages of the different distribution flow types and what factors are most influential on the distribution flow type selection?

2.3 RESEARCH METHODOLOGY

Mitroff et al. (1974) identified four steps for model-based quantitative research. These steps are conceptualization, modelling, model solving and implementation (Figure 2.3). The authors mention common mistakes made in research by taking a short-cut, for instance by following the modelling – model solving – feedback (narrow sense) cycle, where the implementation and conceptualization steps are skipped. The framework helps to make sure all steps in proper research are completed.

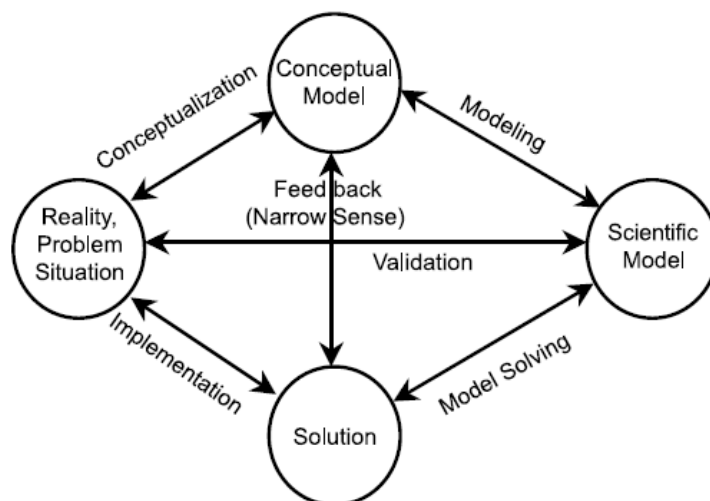


Figure 2.3: Research methodology by Mitroff et al. (1974)

This master thesis will run through these steps, starting with the conceptual model in chapter 4. At that point research questions 1 and 2 can be answered. Note that the conceptual model is based on the work done in the problem description by defining the scope and in the literature review in chapter 3. The quantitative model will be presented in chapter 5, where the functional requirements and the design parameters are identified and research questions 3 and 4 are answered. Model solving and implementation are done in chapters 6 and 7 respectively, where the final research question will be discussed.

3 LITERATURE REVIEW AND BENCHMARK ANALYSIS

This section describes the current state of literature on flow type selection problems. Next to that, a benchmark analysis is performed to investigate how other retailers deal with this strategic question.

3.1 LITERATURE REVIEW

3.1.1 DISTRIBUTION FLOW TYPES

A lot of research has been done on the distribution network designs, meaning the facility location-allocation problem. However, fewer studies covered what the function of a facility should be and how the supply chain should be controlled. Many researchers in this area assume facilities are stock keeping distribution centers (e.g. Zhang et al., 2003; Cordeau et al., 2006; Tsiakis, et al., 2001). Van der Vlist (2007) stated that facilities can also be shipment consolidation points, cross-docking centers or pick-to-zero facilities. His definition of the network design problem is broader than just the facility location-allocation problem. It comprises of the functions of the different facilities in the supply chain network and how goods flow from supplier to outlet.

In an exploratory study based on semi-structured face-to-face interviews with 28 leading European grocery retailers, Kuhn & Sternbeck (2013) categorized four retail distribution flow types that were used most often in practice. The first type uses a single central DC, the second type uses multiple regional DCs, the third type uses both separately and the fourth uses both with an internal consolidation point at the regional DCs. Although Kuhn & Sternbeck (2013) discussed different types of network designs that are applicable in grocery retailing, they only briefly consider what the function of a facility could be and how this will interact with suppliers. The fourth option they mentioned (one central and multiple regional DCs that act as consolidation points) briefly mentions cross-docking. However, a vast body of literature has been written on this topic and found that it has many potential benefits. For instance Shapiro & Wagner (2009), who modelled three options for the distribution from supplier to store: direct store delivery, via DC and via cross-dock. In fact, their model results showed that for their case study more than 20% reduction of total supply chain costs can be achieved. Most of the savings are due to the expansion and increased use of cross-docks in their network, because of more efficient truck utilization. Other authors also named several possible benefits such as shorter delivery lead time, reduction of costs and reduced inventory (e.g. Van Belle et al., 2012; Vogt, 2010). Vogt (2010) classified three different cross-docking options: Cross-dock-Managed-Load, Joint-Managed-Load and Supplier-Managed-Load. The former two are comparable to pick-to-zero (PTZ), while the latter is comparable to what is called pure cross-docking in this research.

Van der Vlist (2007) distinguishes roughly between three distribution flow types. The first is the traditional supply chain, where both supplier and retailer keep inventory. The second variant is comparable to the structure that Wal-Mart uses for many of their products (Stalk et al., 1992). Now the manufacturer keeps inventory and picks the orders on outlet level. The inventory and order picking operation is shifted upstream in the supply chain to the manufacturers. The retailer's cross-dock facility functions only as a shipment consolidation point. The third is called Supply Chain Synchronization (SCS), which is a term that he used to describe his own flow type. This flow type means that the supplier sends its goods immediately after production to the retailer's warehouse. Van der Vlist (2007) argued that the decoupling point should be moved downstream in the supply chain instead of upstream, because this will lead to the overall cheapest supply chain and better customer service as goods are closer to the customer. The main difference between the latter two is the location of the inventory and the order picking activities related to that. SCS pushes inventory to the retailer, which makes the order lead time for outlets shorter compared to the cross-docking option as the inventory is closer to the customer. This is indeed a benefit for SCS as it reduces the risks of not being able to deliver, provided that the warehouse serving a particular outlet has sufficient inventory. The longer lead time is a clear disadvantage for the cross-docking option. Waller et al. (2006) also placed a

critical note at the concept of cross-docking. Because lead times increase, the safety stock at the retail outlets should increase to have the same service level. Holding inventory at the retail outlet costs more than in a DC, which decreases the benefits of cross-docking. Intuitively one could think that there should be a trade-off here. Indeed, as inventory is closer to the customer, it is more dispersed over multiple nodes in the system. This can lead to an imbalance problem as mentioned by De Leeuw et al. (1999). Van der Vlist (2007) claimed to solve this problem by using a 'Carrousel' that allows for fast transshipments between DCs. Nevertheless, placing inventory more upstream in the supply chain allows for risk pooling which is a benefit for cross-docking. Gebennini et al. (2013) argued for moving picking activities upstream. It does increase transportation costs, but the decrease in other operational costs will be higher. The benefit of SCS is that it significantly reduces transportation costs because distribution is synchronized to production which results in much more full pallets and full truckloads. In case of pure cross-docking, suppliers have to ship outlet-specific carriers to the retailer's cross-docks. It is more likely that these carriers are not full and because the outlets pull the demand from the supplier, goods must be shipped every day, whether the trucks are full or not. Of course the cross-docking facility will consolidate, but Van der Vlist (2007) argued that this will never result in pallets and truckloads as full as in the case of SCS. It also involves more time pressure when cross-docking with heavy workload peaks that make workload scheduling complicated and leaves more room for mistakes (or less time to correct them). Waller et al. (2006) found that the relative benefit of cross-docking decreases when the number of outlets increase. However, Waller et al. (2006) did not take into account costs of transport, handling and waste which might explain their outcome since it only incorporated inventory costs. Gerbecks (2014) pointed out an important condition for cross-docking and found that suppliers are only willing to deliver via pick-to-zero at a sufficient number of retail outlets. Perhaps the biggest objection for SCS is that it mainly benefits the supplier because of the absence of inventory and it allows for full shipments. Retailers need to negotiate that the supply chain-wide benefits arising from SCS should be equally divided over both parties.

3.1.2 SUPPLIER CHARACTERISTICS AND PERFORMANCE MEASURES

Flow type selection is done based on certain product and supplier characteristics. Although many factors were identified, a few stand out most in the literature. Especially demand rate, because this determines whether a truckload is full or not, and demand uncertainty and variability, because this determines to what extent the imbalance problem is present and how it can be solved (Zwaan, 2015). In the case of perishables, also the shelf life is a distinguishing factor. Next, when selecting the best flow type, its performance should be measured. Chopra (2003) made a distinction between two types of performance characteristics, a cost and service factor. It seems that every facility from supplier to retail outlet has four types of costs; inventory, handling, waste and fixed facility costs and in between these facilities there are transportation costs. Note that the fixed costs for suppliers' production facilities are not relevant, since these costs are present in every option. The service factor (Chopra, 2003) includes the response time, or delivery lead time. This is of critical importance for retail outlets because they have a limited storage capacity. Storage both on the shelves as in the backroom is scarce (Eroglu et al. 2013), while availability should be as high as possible. Furthermore, in order to have a product as fresh as possible on the shelves and to prevent waste, for perishable items the inventory in outlets is likely to be lower compared to regular items, which requires more frequent deliveries. The delivery lead time (order lead time for the outlet) is therefore a performance measure, since it is influenced by the type of network structure. Van der Vlist (2007) endorsed this and claimed that his structure (Supply Chain Synchronization) puts inventory closest to the customers, such that short lead times and high service levels can be achieved. Service levels in retailing can be seen as on-shelf availability (OSA), which has been a major cause of concern to grocery retailers in the past decade (Ferne & Grant, 2008). It is defined as the probability of having a product on stock, or in case of grocery retailing, on the shelf (Chopra, 2003). Furthermore, Kuhn & Sternbeck (2013) named freshness requirements, which in the case of perishables is certainly an issue that influences the selection of a flow type. Products that require a high degree of freshness, also

require shorter cycle times (time it takes to go through the supply chain) and shorter delivery lead times.

3.2 BENCHMARK ANALYSIS

As retailers use different types of distribution systems, it is interesting to see what considerations have been made in the development of their distribution system. Supply chains have developed roughly in four stages: direct store delivery before the 1980s, centralization in the 1980s, just-in-time in the 1990s and today cooperation is seen as the next step to improve retail logistics (Ferne & Sparks, *Tesco's supply chain management*, 2009). Due to limited storage capacity in outlets, increased customer service levels and the perishable nature of many products, smaller and more frequent deliveries to outlets are required. To decrease the lead time from production to shelf, whilst delivering at high frequency and efficiency, Tesco has decided many years ago to have stockless depots for their chilled supply chain. They observed that duplicate inventory was held both at the supplier and at their DCs. Therefore, most suppliers now deliver exactly the aggregated demand for all outlets to Tesco's stockless depots, from where it is redistributed to the outlets, combining it with other cargo. With this stockless supply chain (stockless for Tesco, not necessarily for the supplier), shorter lead times, reduced system inventory and better control and visibility were realized. Soon after the successes of this system became apparent, other retailers in the United Kingdom such as Asda, Sainsbury and Waitrose followed and implemented a similar supply chain (Ferne & Sparks, *Tesco's supply chain management*, 2009).

Tesco has cut inventory at a downstream point of the supply chain. However, similar results can be expected when inventory is cut at a link upstream of the supply chain: at the supplier. Albert Heijn is simplifying its fresh food supply chain by creating a network of national category DCs each dedicated to a fresh food category so suppliers deliver to one single, central location. Products are sent immediately after production to this national category center, from where case packs are picked on outlet level and sent to the outlets. Some products that already move very quickly through the supply chain will be supplied through the current distribution system via RDCs. Delhaize uses a similar way to distribute their fresh products. Suppliers send their products to a central warehouse, from where the products are sent to the outlets. This view on supply chain management for fresh products is what Van der Vlist (2007) called Supply Chain Synchronization.

4 CONCEPTUAL MODEL

The conceptual model introduces the system that is modelled. It addresses the functional requirements and design parameters. Firstly, all possible distribution flow types are identified. Then, based on qualitative arguments, a selection of the most promising flow types is made which will be modelled quantitatively in chapter 5. Also, the most relevant costs are identified that will be used to evaluate the quantitative model.

4.1 DISTRIBUTION FLOW TYPES

Based on a literature study as a preparatory part of this master thesis (Zwaan, 2015), the initial range of flow types can be identified which are schematically given in Figure 4.1.

The left column is called primary distribution and deals with the logistics of the supplier. The supplier has three options to handle its products. It can send its products immediately after production to their customers (option '0'), it can outsource its logistic activities to a logistic service provider (LSP), who will most likely store the products in a warehouse together with other customers (option '1'). Or the supplier can store the products after production in their own warehouse and deliver to customers from stock (option '2').

The middle column, secondary distribution, deals with the logistics of the retailer on national level, meaning that the retailer may use a NDC. Again, option 0 means the warehouse is skipped in the supply chain and option 2 means storage at an NDC. Option 1 requires some additional explanation, because now the retailer uses its NDC as a stockless depot. Stockless means that goods only pass through and there will be no inventory left after the order cycle. The goods only enter the distribution center for consolidation purposes, which are usually referred to as cross-docking activities. As was mentioned in the literature review, retailers can use several types of cross-docking. Jumbo uses the following definitions: cross-dock means that the supplier picks at outlet level and sends outlet-specific carriers to the stockless depot. At the stockless depot the carriers for that outlet are combined with carriers from other suppliers and are sent to the outlet. Transito is similar in that the supplier picks at outlet level, but now in outlet-specific boxes. At the stockless depot, the carriers (containing multiple outlet-specific boxes) are sorted and restacked on outlet-specific carriers. Note that cross-dock and transito can be used simultaneously on a daily basis. A supplier combines orders on outlet level and stacks them on a carrier. When the volume per outlet is high, there is no need to stack multiple outlets on one carrier to save on transportation costs (transito) and to keep outlets on a separate carrier is less costly (cross-dock). At the retailer DC, both cross-dock and transito carriers will arrive. By using a simple identification trigger, for instance a colored sticker, the employees at the retailer DC can immediately see the difference and split the two streams. Put-to-zero (PTZ) is a flow type in which the supplier picks an order for the total aggregate outlet demand. This pallet is sent to the stockless depot, where the pallet moves from outlet to outlet on a floor containing all outlets. When an outlet needs this product, it is picked from this moving pallet. At the final outlet, the pallet is empty (hence the term put-to-zero). Pick-to-zero is a similar alternative where pallets have a fixed location and carriers of outlets move from pallet to pallet, thereby having the same physical lay-out as traditional stock-keeping. Table 4.1 summarizes the meaning of the signs 0, 1a, 1b and 2 which will be used throughout this report to indicate the distribution flow types.

Table 4.1: Meaning of signs for composition of distribution flow types.

Sign	Abbreviation	Meaning
0	Not applicable	DC is skipped, keeping stock is not applicable.
1a	XD-TR	A combination of cross-dock and transito is applied at the DC.
1b	PTZ	Pick or put-to-zero is applied at the DC.
2	Stock	Stock is kept at the DC.

The right column in Figure 4.1, is called tertiary distribution. It is the final stage before the goods are received at the outlet. Similar to secondary distribution, it can either skip the RDCs (option

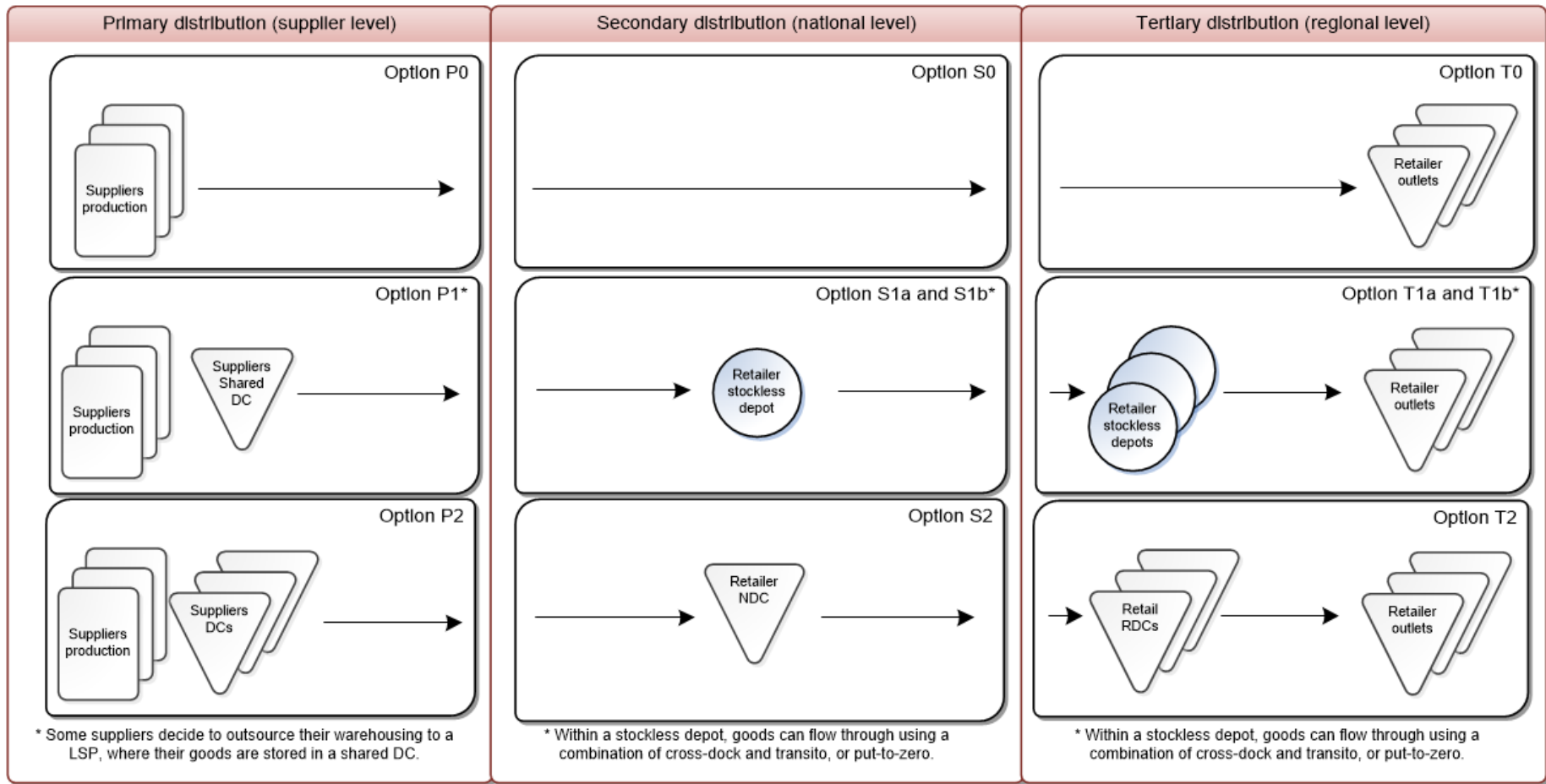


Figure 4.1: Distribution flow types

'0'), apply pick-to-zero or a combination of cross-dock and transito (option '1'), or keep stock at the RDCs (option '2'). When combining signs, a flow type is built. For instance: flow type 2-0-1a means keeping stock at the supplier, skipping the NDC and apply XD-TR at the RDCs.

4.2 INITIAL COST ANALYSIS

In this section rough cost calculations are made in order to decide which costs are most important to model in detail.

From the literature review (Zwaan, 2015) a number of cost factors were identified that are influenced by the flow type selection. These are fixed facility, inventory, handling, waste and transport. Figure 4.2 shows how these costs are split up. Note that this does not include supplier costs, but the cost break-down gives a good indication of which costs are most important. This cost division is based on the total assortment of Jumbo and includes the waste costs in outlets as a result of expiring the best-before-date. Obviously, for the fresh assortment, the costs for waste are likely to constitute even a bigger portion of the total supply chain costs due to their perishable nature. Furthermore, less inventory is held for fresh products in comparison with regular non-perishables, such that inventory for fresh products is even lower. On the other hand, handling costs at the outlets are not included.

Current retailer supply chain costs

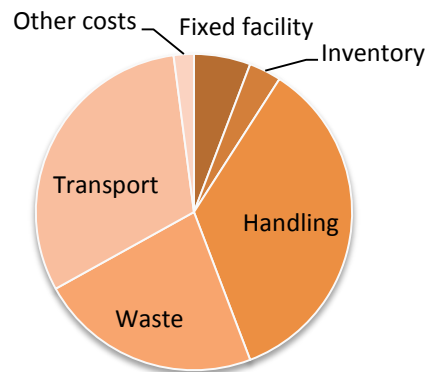


Figure 4.2: Current retailer supply chain cost breakdown (supplier not included)

A quick analysis showed that mainly transport, handling and waste costs constitute the total supply chain costs. Note that the term supply chain costs is subject to different interpretations, but here the costs that are dependent on the flow type selection are calculated. Given that these three cost factors are most important, their drivers should be investigated more in-depth compared to the other cost drivers. For instance, it is not very interesting to find out what exactly the interest rate should be, as this only has limited effect on the total costs. On the other hand, the utilization of carriers and trucks has a big influence on the handling and transportation costs, which represent a big portion of total costs. This allows us to be more detailed about certain variables, while for others a rough estimate is sufficient. Figure 4.2 is in line with the findings of Van der Vlist (2007) and Van Zelst et al. (2009), who found that transport and handling constitutes the largest part in retail supply chain cost. Note that these papers deal with non-perishables, which explains why waste costs is not present in their analysis.

The total costs can be split up in two dimensions. It will be interesting to see the costs not only for the retailer, but for the entire supply chain. Therefore the supplier costs are also taken into consideration. Furthermore, it will also be interesting to see what the costs will be for the supplier, given a certain flow type. When a change in flow type is desired, the supplier might be confronted with different activities and costs than before. In the negotiation stage it will be interesting to know what this difference will likely be for the supplier. For that reason, the costs are not only split up vertically into the categories as discussed above (handling, transport and waste), but also horizontally such that these costs can be separated for each stage in the supply

chain (supplier, NDC, RDC and outlet). This split is equivalent to the split made for flow types, as can be seen in Figure 4.1. Primary costs consist of all costs for the supplier, secondary costs for all costs at NDC level and tertiary costs for all costs at RDC and store level. Again, note that only the costs that are dependent on the flow type are evaluated, so for instance inventory costs at outlet level are not taken into account. These costs are always present, no matter what distribution flow type is chosen.

4.3 FUNCTIONAL REQUIREMENTS

The research question of this master thesis is: *“What are the best distribution flow types for fresh products in a retail supply chain such that overall costs are lowest, while maintaining or improving freshness at the outlet with a predefined service level?”*. The functional requirements that are implicitly present in this question are related to costs, freshness and service level.

Costs

Total supply chain costs should be lowest, meaning that the model includes all relevant costs (facility, inventory, handling, transport and waste) on all levels (supplier, retailer DCs and outlets) should be minimized.

Freshness

As freshness is one of the seven guaranties of Jumbo, the company tries to improve on this as well. So the distribution system should be designed such that items at least keep the current ‘best before’ dates. Or in other words, the minimum remaining shelf life (RSL) in outlets should be at or above the norm as defined by Jumbo.

Service level

The replenishment logic at Jumbo is a (R, s, nQ) -system, where outlets order an integer multiple of a fixed base replenishment quantity (n case packs) and inventory is reviewed periodically. There are multiple measures for product availability, or service level. Fill rate, which is the long-term fraction of demand delivered immediately from stock, is impossible to measure in retail as demand is unknown, only sales are known. However, other measures such as ready rate (Silver et al., 1998) measure product availability continuously over time, which can have flaws due to data inaccuracy. Whatever measure is taken to calculate service level, in (R, s, nQ) -systems both lead time and review period are important variables that determine service level. And, they can be influenced by the flow type selection, as opposed to variation in demand. Furthermore, service levels in outlets are difficult to quantify, as there is currently no standard on product level. Having enough inventory for consumers is the responsibility of outlets which place their orders in the distribution system. Outlets have limited possibilities to keep safety stock due to storage capacity restrictions and freshness requirements. As outlets have to deal with demand uncertainty, they should be able to order at high frequency and get delivered within a short lead time. Therefore, the distribution system that is to be designed should be able to perform at least at the current level in terms of delivery frequency and lead time, meaning that a maximum lead time of 24 hours is assumed. One could also say that the service to the outlets should be equal to the current situation, so we do not try to optimize delivery frequencies or lead times. Delivering multiple times a day is not considered to be an improvement on freshness either. Concluding, in order to meet current service levels, outlets should be able to order once a day at a fixed review period and get delivered within 24 hours after they have placed their order.

4.4 DESIGN PARAMETERS

The design parameters that can be influenced are guided by the definition of the scope and the functional requirements. In this research, the distribution flow type selection is the key decision variable. This section describes how exactly this will be done.

4.4.1 PRODUCT AND SUPPLIER CHARACTERISTICS

This section deals with sub-question 1: *Based on product and supplier characteristics, what relevant product classes can be identified?* Product and supplier characteristics are likely to influence the flow type selection. De Leeuw et al. (1999) identified product, process and market (PPM) characteristics that have an influence on the distribution control decisions. These are for instance product value, product density, production batch size, obsolescence risk, length of supply chain, required customer service, demand uncertainty, demand variation and demand rate. Although distribution control decisions are different from flow type decisions, these characteristics are still useful to determine what product and supplier characteristics will likely influence the appropriate flow type. As was seen in previous literature (Zwaan, 2015), especially demand rate is an important factor that influences this decision. The demand rate determines the utilization of carriers and trucks, which has an influence on transport and handling costs. In the case of perishables, also the shelf life is a distinguishing factor. Waste is likely to be higher when shelf life is shorter and due to this characteristic more frequent deliveries need to be made such that it also influences the transport and handling costs.

Van Donselaar et al. (2006) defined remaining shelf life (RSL) as the number of days a product is still available for consumption starting from the moment the product arrives in the supermarket. They distinguished between days-fresh (9 days of RSL or less), weeks-fresh (10-30 days of RSL) and non-perishables. In this paper the same definition for RSL is used, but the separation between days-fresh and weeks-fresh is set at 5 days. Weeks-fresh have a RSL of between 6 and 10 days. Based on simulation results of Van Donselaar and Broekmeulen (2012) the median for outdating of products with a RSL of 5 days or less is more than 5%. As expected, waste fractions decrease as the RSL increases. When the RSL is 10 days, the median of waste has decreased to less than 1%. This is in line with empirical data, which shows that for fast and medium moving items waste is less than 1% on average when RSL is 10 days or more. For slow-movers this percentage is higher, but also decreases as RSL increases. As days-fresh products have higher waste costs, it might be interesting to consider a different flow type based on RSL or demand rate. Therefore to split a suppliers' assortment into product classes and assign different flow types to a single supplier might seem to be a logical option. Nevertheless, it is decided to only have one flow type per supplier for other reasons, which will be explained next.

Given that transport constitutes a large portion of total costs, distances from supplier to delivery points and the utilization of a truck are significant cost drivers. Combining multiple product classes is therefore desirable to increase truck utilization. Some flow types are difficult to combine in transport due to different loading units (carriers or pallets) or due to different delivery moments among flow types. Note that the utilization of loading units will also be lower. Hence, allowing for multiple flow types per supplier will likely increase transportation costs. Having a single flow type will still allow suppliers to combine fast-movers and slow-movers, even though the latter are not ordered every day. On the other hand, combining products with different remaining shelf lives may result in less freshness when delivery frequency is low. However, for most suppliers applies that their entire assortment falls within one of the three perishability categories. Only 10% of the suppliers have a significant number of products in multiple categories. Finally, also from an implementation perspective it is difficult to let suppliers deliver through multiple flow types, because the supplier should be able to distinguish between products when delivering. Therefore it is decided to have only one flow type per supplier location. For those suppliers where it might be interesting to deliver through multiple flow types a separate case study can be started to investigate the possibilities. However, this is considered out of scope as for most suppliers this will not be interesting. An additional advantage of this decision is that the modelling will become much less complex. Note that

suppliers operating under a holding with different production locations will be regarded as separate suppliers.

4.4.2 RELEVANT FLOW TYPES

This section deals with research question 2: *What relevant distribution flow types can be identified?* Due to the large range of flow types that can be identified and the large number of input variables, there is a risk of creating a very complex model that is difficult to analyze. Instead of evaluating all possible options, the number of which will grow exponentially, it is better to evaluate only the most influencing factors. For that reason, in sub-question 2 we first aim to identify only the relevant flow types. This will allow us to focus on the relationships that are crucial in the distribution flow type selection. Figure 4.1 provides a schematic overview of the possible flow types on three levels: supplier, NDC and RDC. A flow type can be built when combining different blocks. Two examples are given in Figure 4.3. Note that flow type 2-1-0 actually consists of two options, namely 2-1a-0 for a combination of cross-dock and transito and 2-1b-0 for put-to-zero. The same holds for flow type 0-2-1.

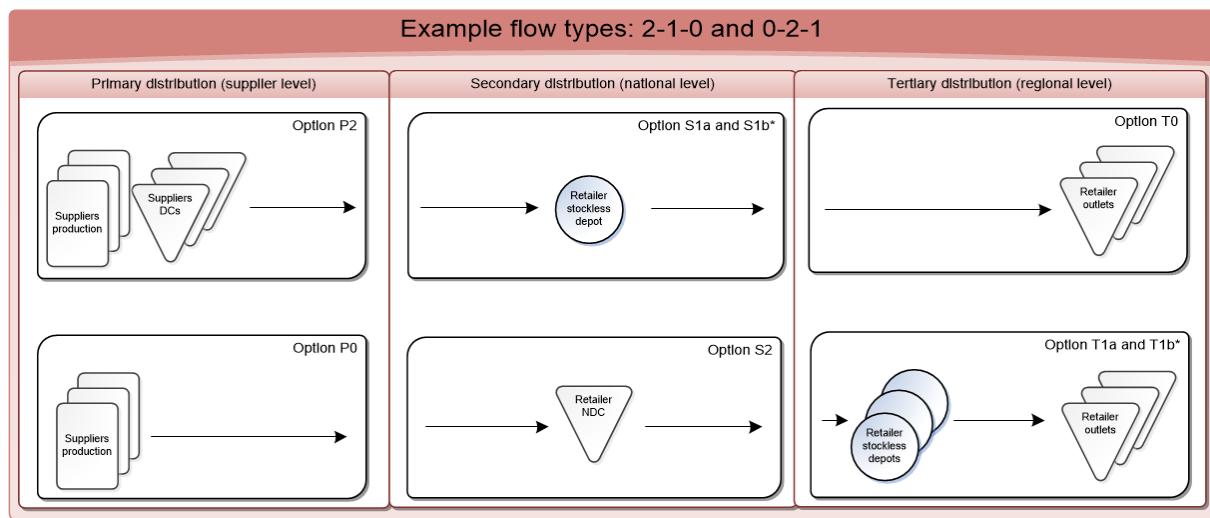


Figure 4.3: Flow type examples

Theoretically there are $3 \times 4 \times 4 = 48$ flow types possible for each supplier. However, most flow types are considered impossible or undesirable due to the functional requirements. Initially there are 9 flow types that will be considered which are listed in the table below. The number of stock points in the system is for every flow type exactly one (contains a '2'). Having no stock point at all (e.g. flow type 0-0-0) is considered impossible because the lead time of 24 hours to the outlets is very unlikely to be met. Having multiple stock points in the system (e.g. 2-2-0) is considered to violate the freshness requirements. Besides, this will add costs such as handling, inventory and waste compared to flow types with only one stock point. This has also been discussed previously in the literature review (Zwaan, 2015), where a comparison between two systems is made: one with stock at the supplier and one with stock at the retailer. Van der Vlist (2007) made a comparison between flow type 2-1-0, the 'Walmart variant', and 0-2-1, which he called Supply Chain Synchronization. This comparison, which was also discussed in the literature review, can be seen as stockless solutions in order to cut inventory out of the supply chain and thereby increasing freshness and reducing costs. The flow types are either stockless for the retailer (e.g. 2-1-0 or the 'Wal-Mart variant') or stockless for the supplier (e.g. 0-2-1 or 'Supply Chain Synchronization'). For a more in-depth discussion on the differences between stockless and stock-keeping flow types, see Appendix A.

Furthermore, a few flow types can be eliminated based on qualitative arguments. Flow type 0-2-1b does not make sense, as inventory is already at the national level of the retailer, so the retailer might as well pick on outlet level at the NDC (0-2-1a), reducing the handling costs by preventing picking twice. On the other hand, flow type 2-0-1b is considered, as the supplier

might benefit from the pooling effect when having multiple customers. Both flow types 2-1a-1b and 2-1b-1b are also considered to be unnecessarily costly as picking activities take place twice. On the other hand, flow types 2-1a-1a and 2-1b-1a are taken into account even though there is some extra handling involved. However, in this case the possibility of transport consolidation benefits exist. Flow type 2-0-0 (direct outlet delivery) is considered undesirable and expensive, because Jumbo prefers to let suppliers deliver at a warehouse to limit the number of drops at the outlets. This not only has cost implications, but also regulatory restrictions and nearby residents complaining about the noise. Furthermore, when applying direct store delivery it is more difficult to monitor quality. Note that flow types containing 'P1' (e.g. 1-0-1a) are not among the flow type options. This would involve many interdependencies among suppliers such that the model becomes very complex. Besides, it is very difficult to make assumptions on which suppliers are willing to cooperate with other suppliers and which suppliers will outsource their logistic operations to which logistic service providers.

The number of possible flow types is not only limited due to functional requirements, but it is also supplier-specific. Some suppliers might not be able or willing to supply through a certain flow type. For these suppliers, the range of possible flow types is smaller. The supplier-specific range of flow types will be ignored, assuming that all suppliers are willing and able to supply through one of the flow types in Table 4.2. The model will be built such that this assumption can be relaxed.

Table 4.2: Design parameters (flow types)

Stockless for supplier	Stockless for retailer
0-2-0	2-1a-0
0-2-1a	2-1b-0
0-0-2	2-1a-1a
	2-1b-1a
	2-0-1a
	2-0-1b

5 QUANTITATIVE MODEL

This section describes the quantitative model, which is based on the conceptual model. First the modelling approach is discussed, which answers research question 3: *What modelling approach to evaluate relevant supply chain scenarios is appropriate?* Then the model assumptions are listed. Finally, this section will build on the conceptual model and the initial analysis by modelling all relevant costs, which answers research question 4: *What are the relevant performance measures in terms of costs and service and how can they be evaluated?*

5.1 MODELLING APPROACH

Models are representations of part of reality as seen by the people who wish to use models to understand, change, manage and control that part of reality in some way or another (Pidd, 1999). Experimenting with the actual supply chain by testing all supply chain scenarios is considered impossible because of the risks and costs involved. Therefore, a mathematical model of the system is made. This provides the possibility to evaluate numerous scenarios on countless performance indicators, despite the inability of precisely predicting the feasibility of the model in real-life (Van der Vorst, 2000). Within the mathematical modelling approach, one can choose between an analytical versus a simulation model. According to Law and Kelton (2000), most real-world problems are too complex to allow for analytical modelling and should preferably be studied by means of simulation. Especially when systems contain stochastic elements, they become too complex for analytical evaluation. On the other hand, the advantages of analytical models are the conciseness in problem description, closed form solutions, ease of evaluating the impact of changes in inputs on output measures, and in some cases the ability to produce an optimum solution (Van der Vorst, 2000). As this is a strategic study, the aim is to provide conceptual insights in the differences between flow types. Analytical modelling is more appropriate for that purpose. Simulation implies that all input parameters and stochastic nature of variables are known. However, this is not the case and with an analytic model it is possible to find upper and lower boundaries of the input parameters and variables. Finally, simulation is very time consuming, which is at the expense of the quality of the model given the limited amount of time for this master thesis. Therefore, an analytical model is built.

5.2 MODEL ASSUMPTIONS

This section lists a number of assumptions that are used in the model.

- Demand is assumed to be deterministic and equal to supply.
- A week pattern in demand is ignored.
- Case pack sizes (number of consumer units per case pack) are assumed to be constant and are equal to the current settings.
- The delivery schedule to outlets is assumed to be constant and is equal to six deliveries per week. Although there are a few exceptions, this is current practice for the fresh assortment.
- Outlets are assigned to a regional distribution center as is currently the case. The model will not optimize on this.
- The number of deliveries from suppliers to a DC is equal to current practice. For 'stockless for retailer'- flow types this is twice a day, so twelve times per week.
- It is assumed that all items of a suppliers are delivered at a delivery moment. For days-fresh this assumption is safe to make, but for slow moving less perishable items this is unlikely.
- The parameter bpw_s (batches per week) is specified on supplier level, neglecting the fact that some items have a different production interval than others.
- The load factor, i.e. the utilization of a trailer, for movements from supplier to DC are estimated by a factor k , which is explained in section 5.6.1.
- The load factor, i.e. the utilization of a trailer, is assumed to be constant for the inter-DC and outlet replenishment transportation movements.

- The number of stops per outlet per day is always equal to one, despite the fact that there are a few outlets that require multiple trucks per day from the fresh assortment due to their high sales volumes.
- Backhauling activities are excluded from the model, such that distances from DC to outlets are travelled twice.
- Suppliers can only choose one flow type and are able to choose between all available flow types. Thereby it is assumed that they are all able to deliver via all flow types within the lead time of 24 hours..
- Only handling and transport costs are included in the model.
- Fixed facility and inventory costs are excluded in the conceptual model. Fixed costs for facilities are regarded as sunk costs, as the number and location of facilities is a different decision. Furthermore, the differences in flow types will not be very big on these two parameters. At most, these costs are moved upstream (to the supplier) or downstream (to the retailer) when switching from flow type.
- Waste costs are not modelled, as it is not expected that they will differ a lot among flow types (section 5.7).
- In the model, Activity Based Costing (ABC) is used to calculate the variable costs. Every cost driver has a base cost, which is multiplied by the volume in number of boxes or cubic meters, the number of pallets or carriers, distance, etcetera. For the handling costs the cost drivers are pallets, carriers, case packs and boxes. The former two are dependent on the decision variables and are approximated in section 0.

5.3 MATHEMATICAL PROGRAM

The model is solved by minimizing the total supply chain costs, which means that the sum of all transport ($COST_t$) and handling ($COST_{h_{ft}}$) costs is minimized, given that each supplier uses one flow type. The handling costs are specified per flow type, while for transport multiple flow types are combined in order to calculate the transport costs.

Objective function:

$$MIN \left\{ \sum_{ft \in FT} COST_{h_{ft}} + COST_t \right\}$$

Constraints:

$$\sum_{ft \in FT} X(s, ft) \geq 1 \quad \forall s \in S \quad [C.1]$$

$$X(s, ft) \in \{0,1\} \quad [C.2]$$

$X(s, ft)$ is the main decision variable, which decides whether or not supplier s uses flow type ft . The \geq -sign should actually be a =-sign because a supplier is only allowed to choose one flow type. However, the former is a set covering problem, which is much easier to solve than a set partitioning problem. The solver will never choose more flow types per supplier, as this means more costs will be made. The binary attribute of the decision variables make this a mixed-integer linear programming (MILP) problem.

In the tables below the sets, input parameters and variables for the model are defined. Note that this is an incomplete version of the model as in this section the aim is to explain how the model works for two example flow types.

Sets

A set is a collection of objects. In the AIMMS modelling language, sets are indexed such that objects can be identified. Sets can be simple sets with strings, simple sets with integers,

relations, compound sets and indexed sets. The following table consists of all sets that will be used in the model.

Table 5.1: Sets

Set	Description
S	Set of suppliers (index = s)
I	Set of items (index = i)
O	Set of outlets (index = o)
O_r	Set of outlets delivered by RDC r (Subset of O)
R	Set of regional distribution centers RDCs (index = r)
FT	Set of flow types, Table 4.1 (index = ft)

Input parameters

The definition of a parameter that will be used in this report is the same as the terminology used in AIMMS. It denotes a known quantity that holds either numeric or string-valued data. Calculation of parameters might be required in advance, but these are independent of the decision variables. Therefore they can be regarded as input parameters for the model. Most parameters will be explained later in this section.

Table 5.2: Input parameters

Parameter	Description
$cp_{i,s,o}$	Average weekly sales in number of case packs (cp) from supplier s for outlet o of item i
$b_{i,s,o}$	Average weekly sales in number of boxes (b) from supplier s for outlet o of item i
$m_{i,s,o}$	Average weekly sales in cubic meters (m^3) from supplier s for outlet o of item i

These three parameters have three indices for the item, the supplier and the outlet. A case pack consists of one or more consumer units. It is the handling unit for the retailer DCs and outlets. So an outlet orders per case pack. A box is usually equal to a case pack, but sometimes multiple case packs are put into a single box.

Variables

Variables are similar to parameters, but the word variable is reserved for unknown quantities. Variables are dependent on the decision variables. For instance the number of carriers that is transported from the NDC to a certain outlet is dependent on the flow type selection of all suppliers. Therefore, variables need to be calculated within the model. Most variables will be explained later in this section.

Table 5.3: Variables

Variable	Description
$c_{ft,o}$	Number of carriers via flow type ft for outlet o

Decision Variables

The main decision variable in the model is $X(s, ft)$ which denotes whether or not supplier s delivers via flow type ft . This binary decision variable is used throughout the model to assign costs to a certain activity or flow type. Since the model is a MILP-model, all constraints and cost functions should be linear.

Table 5.4: Decision variables

Variable	Description
$X(s, ft)$	Binary decision variable that decides whether supplier s uses flow type ft

5.4 APPROXIMATIONS FOR COST DRIVERS PALLETS AND CARRIERS

The cost drivers pallets and carriers are most complicated to calculate, as they are dependent on the decision variables and might differ among flow types.

5.4.1 NUMBER OF PALLETS

The number of pallets that are transported from a supplier to the NDC or the RDCs of the retailer is different for each flow type. The number of pallets only needs to be calculated for 'stockless for supplier'-flow types 0-2-0, 0-0-2, 0-2-1a and for put-to-zero flow types 2-1b-0, 2-1b-1a and 2-0-1b, as is shown in Table 5.5.

Table 5.5: flow types for pallet transportation from supplier to DC

	Stockless for supplier	Stockless for retailer
Pallets to NDC	0-2-0 and 0-2-1a	2-1b-0 and 2-1b-1a
Pallets to RDC	0-0-2	2-0-1b

The 'stockless for supplier'-flow types assume that suppliers send their products immediately after production to the NDC or RDCs. Here the products are kept on stock and picked once outlets have placed their orders. The model requires the input parameters $p_{ft,s}$, which are the weekly number of pallets via flow type ft of supplier s . This is dependent on the number of production batches a supplier has per week. When a product is produced once a week, the supplier can send the total volume of one week to the retailer's warehouse. However, when shelf life is low, more frequent production batches and shipments might be needed. For an extensive analysis on the difference between the traditional supply chain and the 'stockless for supplier'-flow types we would like to refer to Appendix A.

Table 5.6: Input parameters for calculating number of pallets

Parameter	Description
$p_{ft,s}$	Weekly number of pallets from supplier s to the retailer via flow type ft .
$bpp_{i,s}$	Maximum number of boxes per pallet of item i from supplier s .
bpw_s	Average number of production batches per week of supplier s .
$dpw_{ft,s}$	Deliveries per week from supplier s to the retailer when using flow type ft .

From the examples in Appendix A, the following formulas can be derived. Formula [5.1] denotes the number of pallets when the supplier does not keep stock and delivers directly to the NDC after production. The number of pallets for flow type 0-2-1a is exactly the same, while for flow type 0-0-2 minor adjustments are needed to make sure the quantities are sent to the right RDC. The only difference with formula [5.2] is that the latter formula uses the number of deliveries per week. In this case the supplier keeps stock and sends exactly the aggregated outlet orders to the NDC (or to the RDCs in case of flow type 2-0-1b). For these 'stockless for retailer'-flow types, twelve deliveries per week are assumed.

$$p_{0-2-0,s} = \sum_{i \in I} \left(\frac{\sum_{o \in O} b_{i,s,o}}{bpp_{i,s} * bpw_s} + 0,5 \right) * bpw_s \quad [5.1]$$

$$p_{2-1b-0,s} = \sum_{i \in I} \left(\frac{\sum_{o \in O} b_{i,s,o}}{bpp_{i,s} * dpw_{ft,s}} + 0,5 \right) * dpw_{ft,s} \quad [5.2]$$

Note that for every delivery moment, each item gets an additional 0,5 pallet. This is an alternative for rounding up to one pallet. Consider an item with relatively low demand per delivery, say 80 boxes, while a full pallet consists of 100 boxes. This means that 0,8 pallets are needed, which is rounded to one pallet. However, as demand is stochastic, sometimes demand might be 110 boxes. In that case two pallets are required. On average 1,3 pallets are required. The implicit assumption here is that orders are not rounded when placed by the retailer. In reality pallets are usually rounded to full pallets or at least to layers of pallets, especially for items with a high remaining shelf life. Alternative methods to estimate the number of pallets

were explored, but the results of this method were most accurate and has the simplest formula. The alternative methods are discussed in Appendix C.

Production batches per week

The number of batches per week is supplier specific, if not item specific. In order to find out what the number of batches is for each supplier, a short questionnaire is sent out to the suppliers of Jumbo. The aim of this questionnaire was to find out the location of the supplier, its assortment and the average number of production batches for its assortment. The responding suppliers stated how many production batches they run on average for a specific assortment. Usually the assortment of the supplier is limited, such that a single answer (e.g. 3 batches per week for the entire assortment) was given. Therefore, the parameter bpw_s is specified on supplier level, neglecting the fact that some items have a different production interval than others.

Unfortunately not all suppliers responded. Therefore an estimate for the parameter bpw_s needs to be derived. As was mentioned before, it is likely that this parameter depends on the remaining shelf life of the products. When shelf life is low, usually more production batches are required in order to prevent waste. This hypothesis was tested with the answers of the responding suppliers. Most suppliers deliver items that fall into one of the perishability classes as mentioned in section 4.4.1, or at least deliver the greatest part in one class.

The figure shows that suppliers having mainly days-fresh items usually produce an item six times per week, while suppliers of weeks-fresh and less perishables usually have respectively three and two batches. These results form the basis for the assumption on how many production batches a supplier has.

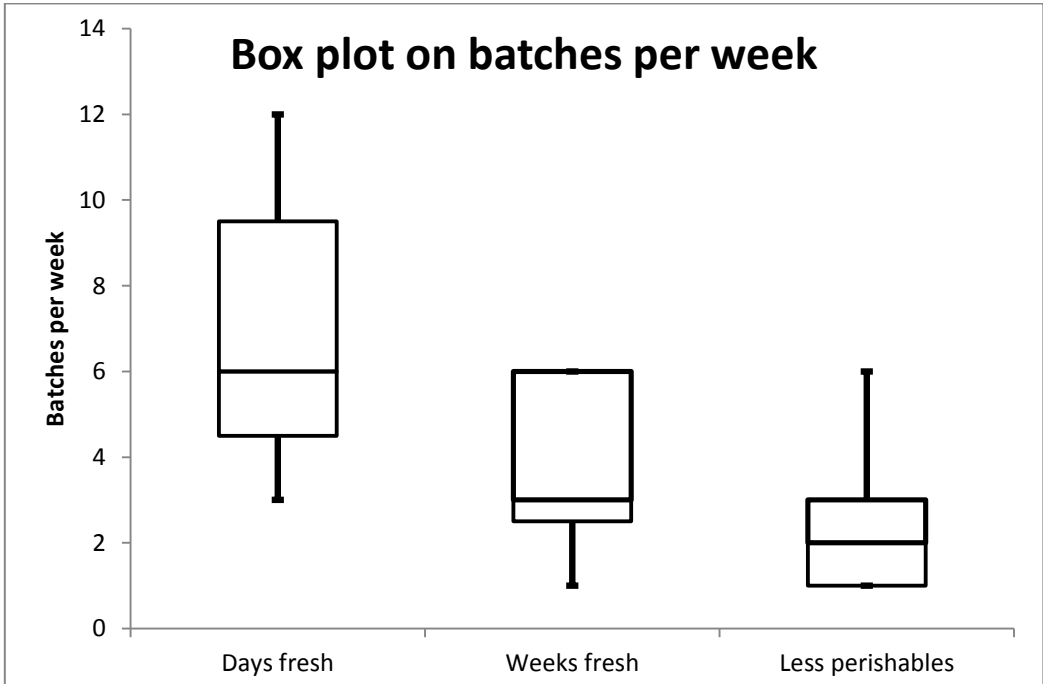


Figure 5.1: Box plot on the number of production batches of responding suppliers

5.4.2 NUMBER OF CARRIERS WHEN SUPPLIER PICKS FOR CROSS-DOCK

The number of carriers when a supplier picks is not dependent on the decision variables, meaning that it can be calculated on supplier level without having to know the flow type selection of other suppliers. As was explained in section 4.1, a combination of cross-dock and transito will be modelled here. This section shows how the split is made.

Table 5.7: Input parameters for calculating number carriers when cross-docking

Parameter	Description
$c'_{XD,s,o}$	Carriers per delivery moment for cross-docking from supplier s to outlet o .
NCC	Net capacity of a carrier in m^3 .
dpw_o	Deliveries per week to outlet o .
$fraction_{XD,s}$	Fraction of volume from supplier s delivered via cross-dock.
$fraction_{TR,s}$	Fraction of volume from supplier s delivered via transito.
$c_{XD,s}$	Weekly number of carriers via cross-dock from supplier s to a DC.
$c_{XD,o}$	Weekly number of carriers via cross-dock to outlet o .
$c_{TR,s}$	Weekly number of carriers via transito from supplier s to the NDC.
$dpw_{ft,s}$	Deliveries per week from supplier s to the retailer when using flow type ft .

$c'_{XD,s,o}$ represents the number of carriers per delivery moment (six delivery moments per week) for cross-docking to outlet o from supplier s . The fraction that will be cross-docked by supplier s is the total volume of cross-docked carriers divided by the total volume of that supplier. The remaining fraction goes via transito (TR).

$$c'_{XD,s,o} = \frac{|\sum_{i \in I} m_{i,s,o}|}{dpw_o * NCC} \quad [5.3]$$

$$fraction_{XD,s} = \frac{dpw_o * NCC (\sum_{o \in O} c'_{XD,s,o})}{\sum_{o \in O} \sum_{i \in I} m_{i,s,o}} \quad [5.4]$$

$$fraction_{TR,s} = 1 - fraction_{XD,s} \quad [5.5]$$

$$c_{XD,s} = dpw_o * \sum_{o \in O} c'_{XD,s,o} \quad [5.6]$$

$$c_{XD,o} = dpw_o * \sum_{s \in S} c'_{XD,s,o} \quad [5.7]$$

$$c_{TR,s} = dpw_{ft,s} * \left[\frac{\sum_{o \in O} \sum_{i \in I} m_{i,s,o} * fraction_{TR,s}}{dpw_{ft,s} * NCC} \right] \quad [5.8]$$

Rounding is possible because this part is left out of the MILP-problem. They can be regarded as input parameters, which are eventually multiplied by the decision variables $X(s, ft)$. These formulas apply to flow types 2-1a-0, 2-1a-1a and 2-0-1a and because the formulas are specified per outlet, they can be used for all three flow types. The only difference is in whether it will be sent to the NDC or the RDCs. In the latter case, the formulas need to be adjusted such that the summation over all outlets in the set O_r is done, which are all outlets assigned to RDC r .

This research assumes deterministic demand, while in reality demand is stochastic. Due to this, the rounding might cause some unwanted effects. Nevertheless, as there are 579 outlets which all have a different sales volumes, this effect is expected to be negligible.

5.4.3 NUMBER OF CARRIERS WHEN RETAILER PICKS (INCLUDING TRANSITO)

Within the distribution centers there are multiple picking sections, which are separated based on their assortment. Some products require a temperature of 13^o Celsius, while others require a temperature of 2^o Celsius. In that case, order picking activities are separated. However, also within one temperature zone multiple picking sections exist. In order to replenish efficiently in the outlets, family grouping is used to prevent carriers with very different types of items. Therefore groups of products (families) with similar characteristics (e.g. dairy) are made. Within the DC, the locations where a family is stored is called a section.

Orders in order picking are split when either a certain volume, weight or number of boxes is reached. Data shows that 95% of the orders are split because the volume capacity is reached. Therefore, calculating with a volume (i.e. $m_{i,s,o}$) is most reliable for estimating how many carriers are required. Formula [5.9] calculates the number of carriers to an outlet required when using a specific flow type, in this example flow type 0-2-1a. It adds up the volume of all suppliers per section per delivery moment to an outlet. Note that this formula assumes all sections have equal volume. Due to family grouping, stacking items among sections is prohibited. However, stacking within a section (e.g. combining two carriers) is done. Based on order picking data a

conversion factor was derived, which can be used to estimate the number of carriers needed when a volume flows through a certain flow type.

As this formula includes a fixed 'cost', which is only activated when volume is greater than zero, the binary decision variable is Y_{0-2-1a} introduced. Constraint [C.3] makes sure this variable is activated when volume is greater than zero, where M is a sufficiently large number. This constant (*Intercept*) is required for the same reason why 0,5 pallets are added to the required number of pallets in formula [5.1] and [5.2]. A carrier that is not full requires the same handling and transport as a full carrier. Each day, for every section-outlet combination, there is a remaining volume that will usually not make a full carrier and needs to be rounded up. Using formula [5.9] is an alternative for rounding up. The formula for the RDC-flow types is similar, only $Sections_{RDC}$ is used instead of $Sections_{NDC}$.

Table 5.8: Input parameters for calculating number of carriers

Variables/parameters	Description
$c_{ft,o}$	Number of carriers via flow type ft to outlet o .
$Section_{NDC}$	Number of picking sections in the NDC.
<i>Slope</i>	Slope of the linear function that predicts the number of carriers.
<i>Intercept</i>	Intercept of the linear function that predicts the number of carriers.
Y_{ft}	Binary decision variable to activate the fixed 'cost' (intercept).

$$c_{0-2-1a,o} = \left(\sum_{s \in S} \left(\frac{\sum_{i \in I} m_{i,s,o}}{dpw_o * Sections_{NDC}} * X(s, 0 - 2 - 1a) \right) \right) * Slope + Intercept * Y_{0-2-1a} \quad [5.9]$$

$$\sum_{i \in I} \sum_{s \in S} \sum_{o \in O} m_{i,s,o} * X(s, ft) \leq Y_{0-2-1a} * M \quad [C.3]$$

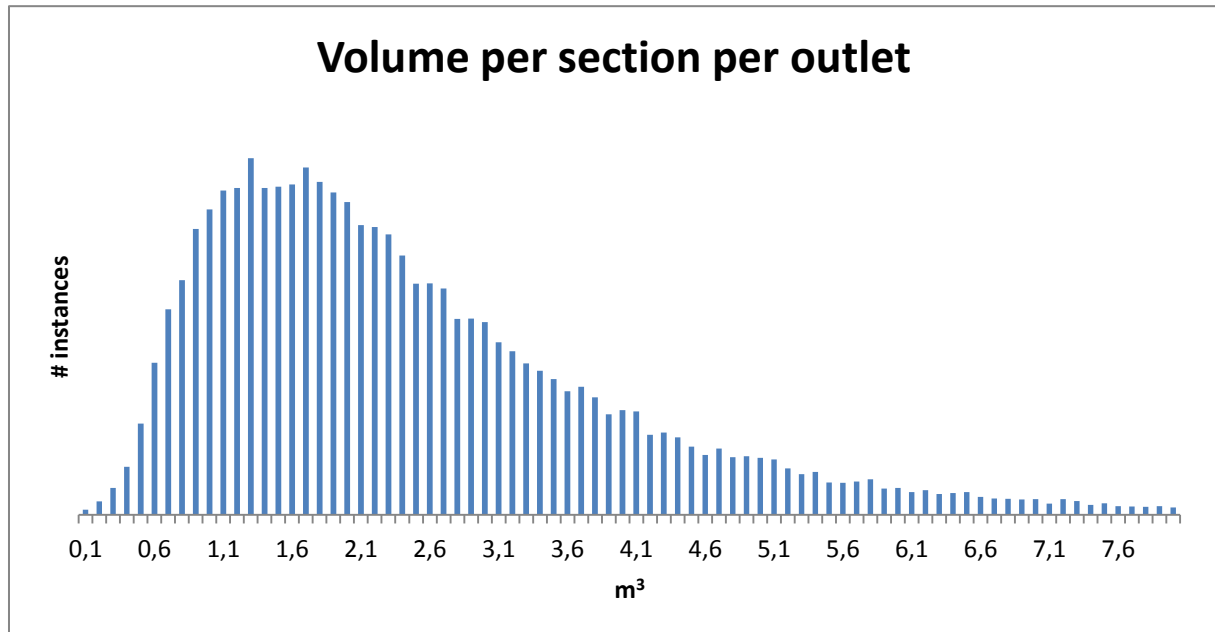


Figure 5.2: Volume per section per outlet

The slope and intercept in formula [5.9] is estimated based on actual data. This shows that the total volume per outlet per section in the current situation is in approximately 95% of the cases between 0,5m³ and 6m³ (Figure 5.2). Between these values, the prediction therefore needs to be accurate. The figure below shows that with this slope and intercept the function predicts the

actual number of carriers very well between 0,5m³ and 6m³ (R² of 99,6%). Note that the approximation slightly overestimates for low volumes (between 0m³ and 0,4m³), but is still relatively accurate (R² of 74,8%). Besides, there are only a few outlets that have such low volumes. The higher volumes also have a good accuracy. Between 6m³ and 8m³ the R² is 90,0%, although there are fewer data points which makes the actual data unreliable.

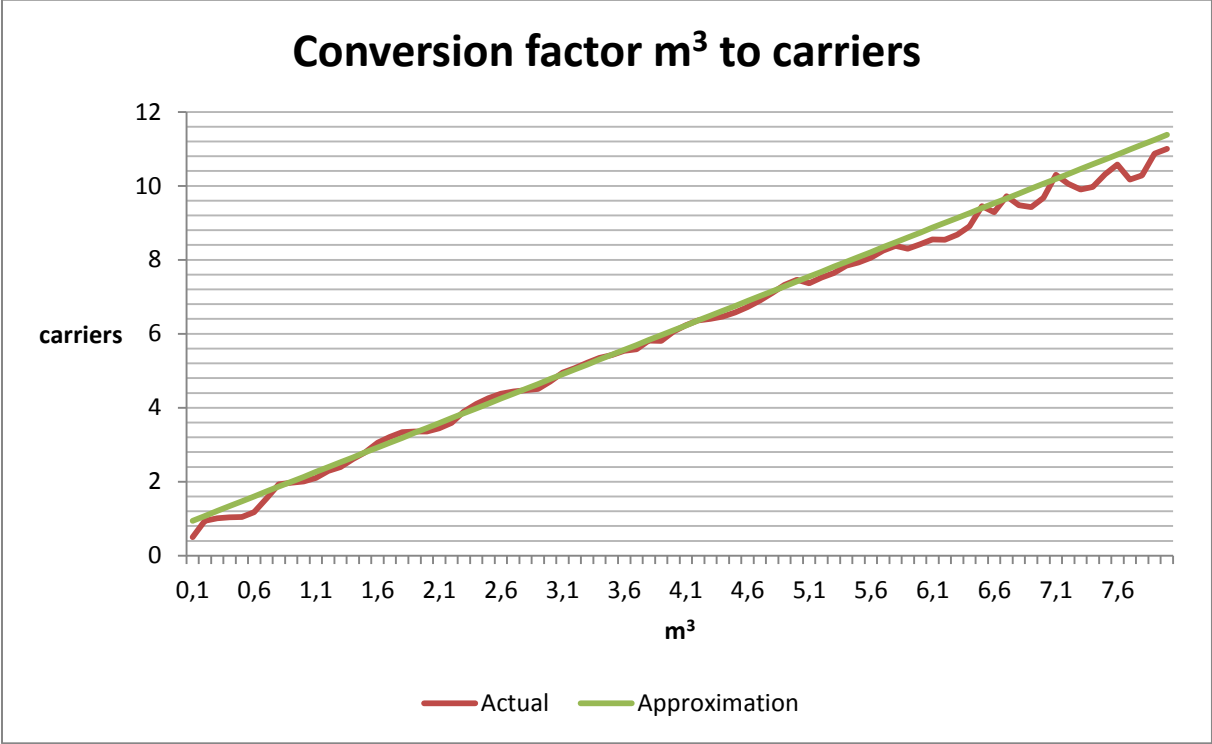


Figure 5.3: Conversion factor m³ to carriers

This approximation of the number of carriers is applicable to all flow types where the retailer picks on outlet level. These are 0-2-0, 0-2-1a, 2-1b-0 and 2-1b-1a at NDC-level and 0-0-2 and 2-0-1b at RDC-level. However, also the transito volume of 2-1a-0, 2-1a-1a and 2-0-1a is used to calculate how many carriers are needed for these flow types. Note that the cross-dock volume that is picked at the supplier is handled separately. Also, it is assumed that the volume of multiple flow types can be combined, in order to benefit from consolidation. Take for instance flow types 2-1a-0 and 2-1b-0. As both flow types require a floor containing all outlets, they can be combined. It is either a pallet or a carrier that moves from outlet to outlet. The same holds at the RDC, where flow types 2-1a-1a, 2-0-1a and 2-0-1b can be combined.

Table 5.9 shows which volumes are combined. An implicit assumption when modelling like this is that all products from all suppliers can be stacked on each other. Furthermore, family grouping is no longer possible when using a single floor. However, in practice this floor might be split into different sections, as is the case for regular order picking in a warehouse for family grouping. This means that for instance suppliers A, B and C are handled on one floor, and suppliers X, Y and Z on another. Allowing such a split will also make it reasonable to assume that stacking goods from multiple suppliers is no longer an issue. The only assumption that remains is that suppliers on one floor deliver on similar packaging units, such that they can be stacked efficiently (e.g. using crates).

Table 5.9: Volumes combined at picking sections

	Stockless for supplier	Stockless for retailer
Volume combined at NDC	0-2-0	2-1a-0 and 2-1b-0
Volume combined at RDC	0-0-2	2-1a-1a, 2-0-1a and 2-0-1b
Not combined	0-2-1a	2-1b-1a

5.5 HANDLING

In this section it is shown how the handling costs are calculated. These are split up for each flow type. Each flow type requires certain input parameters. Next, within the model these input parameters are used to calculate the costs at every stage in the supply chain (supplier, NDC, RDC and outlet), based on the decision variables.

After producing or importing a product, it needs to be stacked on some kind of loading unit, usually a pallet. Therefore, a pallet should always be stored in a warehouse, temporarily kept on a floor or at least being moved from the production floor before it is shipped to the retailer. This holds for all flow types, so these costs are not taken into account. As a starting point for handling it is assumed that a supplier has an item on a pallet either in stock or at a floor. From there, handling activities need to be done in order to move products to the outlet. These activities are different for each flow type. Also the base costs of these activities are different. The base cost of each activity is indicated with an S, R or O, meaning that these costs are for the supplier, the retailer (distribution centers) or the outlet. Each base cost has a cost driver as well, which is for instance the number of pallets. So the base cost for bulk picking one pallet at a supplier (S1) will be multiplied by the number of pallets that need to be picked.

The decision has been made to use Activity Based Costing because the cost drivers are usually dependent on the flow type selection. In that way, the differences between flow types are implicitly present in the cost functions. It also allows to perform sensitivity analyses by changing the base costs. The handling costs for two flow types (0-2-1a and 2-1b-0) will be discussed and serve as an example for other flow types.

Table 5.10: Handling activities for flow types 0-2-1a and 2-1b-0

Flow type	Base cost	Cost level	Handling activity	Cost driver
0-2-1a	S1	Supplier	Bulk picking of pallet	# pallets
	S2	Supplier	Loading a pallet	# pallets
	R1	Retailer NDC	Unloading a pallet	# pallets
	R2	Retailer NDC	Storing and replenishing a pallet	# pallets
	R3	Retailer NDC	Picking at outlet-level	# case packs
	R4	Retailer NDC	Loading a carrier	# carriers
	R5	Retailer RDC	Unloading a carrier	# carriers
	R6	Retailer RDC	Distribute carriers	# carriers
	R4	Retailer RDC	Loading a carrier	# carriers
	O1	Outlet	Receiving a carrier	# carriers
2-1b-0	S5	Supplier	Bulk picking of pallet for PTZ	# pallets
	S2	Supplier	Loading a pallet	# pallets
	R1	Retailer NDC	Unloading a pallet	# pallets
	½ R2	Retailer NDC	Replenishing a pallet	# pallets
	R8	Retailer NDC	Picking at outlet-level (PTZ)	# case packs
	R4	Retailer NDC	Loading a carrier	# carriers
	O1	Outlet	Receiving a carrier	# carriers

Example 1: Flow type 0-2-1a (stockless for supplier)

This flow type means that suppliers send their products immediately after production to the NDC. Here the products are kept on stock and picked once outlets have placed their orders. Then they are sent to the RDCs where they will be cross-docked. The required input parameters are the weekly number of pallets via flow type 0-2-1a of supplier s ($p_{0-2-1a,s}$).

The number of pallets calculated in formula [5.1] will be input for the model. The actual costs depend on whether or not this flow type is chosen, as is denoted in formulas [5.10], [5.11], [5.12] and [5.13].

Supplier

Total handling costs for all suppliers via flow type 0-2-1a.

$$COSTh_{SUP,0-2-1a} = (BASE_{S1} + BASE_{S2}) * \sum_{s \in S} (p_{0-2-1a,s} * X(s, 0 - 2 - 1a)) \quad [5.10]$$

NDC and RDC

Total handling costs for NDC and RDC via flow type 0-2-1a.

$$COSTh_{DC,0-2-1a} = (BASE_{R1} + BASE_{R2}) * \sum_{s \in S} (p_{0-2-1a,s} * X(s, 0 - 2 - 1a)) + \\ BASE_{R3} * \sum_{s \in S} (\sum_{o \in O} \sum_{i \in I} cp_{i,s,o} * X(s, 0 - 2 - 1a)) + \\ (2 * BASE_{R4} + BASE_{R5} + BASE_{R6}) * \sum_{o \in O} c_{0-2-1a,o} \quad [5.11]$$

Outlet

Total handling costs for all outlets via flow type 0-2-1a.

$$COSTh_{OUT,0-2-1a} = BASE_{R4} * \sum_{o \in O} c_{0-2-1a,o} \quad [5.12]$$

Total handling costs flow type 0-2-1a

$$COSTh_{0-2-1a} = COSTh_{SUP,0-2-1a} + COSTh_{DC,0-2-1a} + COSTh_{OUT,0-2-1a} \quad [5.13]$$

Flow type 2-1b-0 (stockless for retailer)

This flow type means that the supplier waits for the orders from all outlets in either the first or the second wave (there are two deliveries to the DC per day for the 'stockless for retailer' flow types). Once this is known, the supplier picks exactly the aggregated amount of each product that is required by the outlets. So instead of sending only full pallets or layers to the NDC, the supplier needs to count and stack exactly the amount ordered by the outlets. Therefore another base cost (S5) is used, which will be higher than base cost S1. After assembling the order, it is shipped to the retailer DC where a put-to-zero operation will be in place such that the items are portioned out over the outlets.

The main difference with the former flow type is that put-to-zero does not require storing and replenishing. However, not modelling these costs is not very realistic. The key advantage of put-to-zero is that a pallet is sorted out over the outlets right after it has been received on the dock. It is difficult to imagine how such an operation would take place when many pallets arrive at a DC. Especially for high volumes this is very likely to happen, which results in congestion when no provisions have been taken. A more realistic way of dealing with all these pallets is to (temporarily) store them, which is similar to what happens at flow type 0-2-1a. Another way would be to place the pallets on a picking location and apply pick-to-zero (taking an outlet-specific carrier and move from pallet to pallet, comparable to regular picking). In that way the activity 'storing' is prevented, which is approximately half of the costs of base costs R2 (storing and replenishing a pallet). Pick-to-zero is more expensive than put-to-zero, but more realistic for larger volumes. Again, one could argue whether or not the 'storing' activity can still be skipped when there are many pallets coming in. Therefore, the conclusions regarding these flow types should be addressed carefully. Also, the model assumes a pick-to-zero operation, such that the costs for replenishing a pallet will be incurred by taking half of the costs of R2. The actual costs are dependent on the decision variables $X(s, ft)$ and are calculated with the following formulas.

Supplier

Total handling costs for all suppliers via flow type 2-1b-0.

$$COSTh_{SUP,2-1b-0} = (BASE_{S5} + BASE_{S2}) * \sum_{s \in S} (p_{2-1b-0,s} * X(s, 2 - 1b - 0)) \quad [5.14]$$

NDC

Total handling costs for NDC via flow type 2-1b-0.

$$\begin{aligned}
 COSTh_{NDC,2-1b-0} &= (BASE_{R1} + 0,5 * BASE_{R2}) * \sum_{s \in S} (p_{2-1b-0,s} * X(s, 2 - 1b - 0)) + \\
 &BASE_{R8} * \sum_{s \in S} \left(\sum_{o \in O} \sum_{i \in I} cp_{i,s,o} * X(s, 2 - 1b - 0) \right) + \\
 &BASE_{R4} * \sum_{o \in O} c_{2-1b-0,o}
 \end{aligned} \tag{5.15}$$

Outlet

Total handling costs for all outlets via flow type 2-1b-0.

$$COSTh_{OUT,2-1b-0} = BASE_{O1} * \sum_{o \in O} c_{2-1b-0,o} \tag{5.16}$$

Total handling costs flow type 2-1b-0

$$COSTh_{2-1b-0} = COSTh_{SUP,2-1b-0} + COSTh_{NDC,2-1b-0} + COSTh_{OUT,2-1b-0} \tag{5.17}$$

The formulas in this section illustrate how the handling costs for all flow types are calculated. Although slightly different, most formulas are similar to the ones described above. Each flow type has a set of handling activities that have a base cost and a cost driver, which can be seen in Table 5.10.

5.6 TRANSPORT

There are four types of transportation costs. Costs arising from transporting pallets from supplier to NDC or RDC, carriers from supplier to NDC or RDC, carriers from NDC to RDC (inter-DC) and carriers from NDC or RDC to outlets (outlet replenishment). The load factor, i.e. the utilization of a trailer, is assumed to be constant for the inter-DC and outlet replenishment transportation movements. For movements from supplier to DC it depends on the volume that is being transported.

Table 5.11: Flow types and corresponding transportation costs

Flow type	Supplier -> NDC	Supplier -> RDC	NDC -> RDC	NDC -> outlet	RDC -> outlet
0-2-0*	x			x	
0-2-1a*	x		x		x
0-0-2*		x			x
2-1a-0	x			x	
2-1b-0*	x			x	
2-1a-1a	x		x		x
2-1b-1a*	x		x		x
2-0-1a		x			x
2-0-1b*		x			x

*Deliveries from supplier on pallets

5.6.1 SUPPLIER TRANSPORTATION ON PALLETS

This section applies to all suppliers that deliver on pallets to one of the DCs of the retailer. These are suppliers that use one of the flow types in Table 5.11 indicated with a *. These flow types are indicated by the set FT_{PAL} . The space that is occupied in a truck determines the transportation costs. Current practice is to stack multiple small pallets on top of each other in order to save space in the truck. Therefore, the number of pallets is not equal to the number of pallet positions in a truck. It is considered impossible to calculate the exact number of pallet positions in a truck,

as it depends on how many pallets are stacked and there is no data available on this. Hence, it is assumed that all products can be stacked on top of each other, given that they are kept in boxes or crates. Also, every item has its own pallet so that the space occupied by a pallet is also included. The space occupied by a pallet is equal to 0,072m³, as can be seen in formula [5.18a]. Formula [5.18a] denotes the required space in a truck per delivery moment. This is not necessarily less than one truck, but can also be 2,3 trucks for instance. It calculates the volume per delivery moment, including the space needed for a pallet. In reality there is always a loss in loading, for instance because some products cannot be stacked on top of each other. The loading inefficiency factor (*LIF*) corrects for this. Formula [5.19a] calculates the number of full truckloads (FTL) required for transport. This is not necessarily an integer. If not, it contains a less than truckload (LTL) and represents the portion of a full truckload that has to be paid according to the transport inefficiency factor *k*, which is derived from Van der Vlist (2007). Obviously full truckloads are less expensive per volume than less than truckloads are. For instance, when 20% of the space is used in a truck, the costs for moving this is approximately 40% of a FTL, depending on the transport inefficiency factor *k*. This is illustrated in Figure 5.4, where a value of 0,435 is chosen for *k*. This number was empirically validated via tariff structures of logistic service providers.

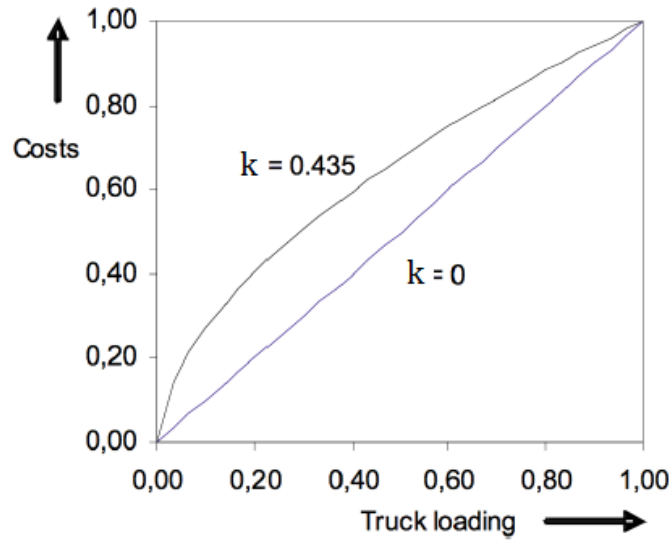


Figure 5.4: Transport inefficiency factor *k* (Van der Vlist, 2007)

Table 5.12: Input parameters for supplier transportation costs (1)

Parameter	Description
$RS'_{ft,s}$	Required space for transport from supplier <i>s</i> to the retailer NDC via flow type <i>ft</i> per delivery moment, either on pallets (PAL) or carriers (CAR).
$Trucks'_{ft,s}$	Required number of FTL-trucks for transport from supplier <i>s</i> to the retailer NDC via flow type <i>ft</i> per delivery moment, either on pallets (PAL) or carriers (CAR).
<i>LIF</i>	Loading (pallet) inefficiency factor.
CAP_m	Capacity of a trailer in cubic meters (m ³).
CAP_c	Capacity of a trailer in number of carriers.
<i>k</i>	Transport inefficiency factor.

$$RS'_{ft,s,PAL} = \frac{(\sum_{o \in O} \sum_{i \in I} m_{i,s,o} + 0,072 * p_{ft,s}) * LIF}{dpw_{ft,s}} \quad [5.18a]$$

$$Trucks'_{ft,s,PAL} = \left\lfloor \frac{RS'_{ft,s}}{CAP_m} \right\rfloor + \left(\frac{RS'_{ft,s} - \left\lfloor \frac{RS'_{ft,s}}{CAP_m} \right\rfloor * CAP_m}{CAP_m} \right)^{1-k} \quad [5.19a]$$

Transportation costs components

Trucking costs consist of three components: travel costs, stopping costs and loading/unloading costs. For the first component, a kilometer price and an hourly wage of driver and truck is used, which is dependent on the distance and speed that is travelled by a truck. For that reason it is a function of the distance between a supplier and a DC. The distance travelled decides for instance how much fuel is used. The time for travelling is dependent on the speed, which is dependent on the distance as well. The longer the distance, the higher the average speed. See Appendix B for an elaboration on this.

The stopping component includes a fixed time for stopping per trip for docking, waiting and signing papers. Transportation costs from supplier to DC are based on the number of required trucks ($Trucks'_{ft,s}$), which was derived by using formula [5.19]. Within the transport inefficiency factor k , the costs for extra stops due to combining multiple shipments is already included. So stopping costs are included in the product of $Trucks'_{ft,s}$ and $Travelcosts_{s,r}$, which are defined in formulas [5.19] and [5.20].

Loading and unloading is dependent on the number of carriers or pallets being transported.

Table 5.13: Input parameters for supplier transportation costs (2)

Parameter	Description
$d_{s,NDC}$	Distance from supplier s to the retailer NDC.
$Travelcosts_{s,NDC}$	Travel related transportation costs from supplier s to the retailer NDC.
$speed_{s,NDC}$	Average speed from supplier s to the retailer NDC.
$Tariff_{KM}$	Transportation costs per kilometer.
$Tariff_{hour}$	Hourly wage for driver and truck.
$Costs_{(un)loading}$	Costs for loading and unloading, either pallets (PAL) or carriers (CAR).
$COSTt_{s,NDC}$	Transportation costs from supplier s to the retailer NDC, either on pallets (PAL) or carriers (CAR).
l_p	Number of pallets loaded per hour.
u_p	Number of pallets unloaded per hour.
l_c	Number of carriers loaded per hour.
u_c	Number of carriers unloaded per hour.

$$Travelcosts_{s,NDC} = d_{s,NDC} * Tariff_{KM} + \frac{d_{s,NDC}}{speed_{s,NDC}} * Tariff_{hour} \quad [5.20]$$

$$Costs_{(un)loading,PAL} = \sum_{ft \in FT_{PAL}} (p_{ft,s} * X(s, ft)) * \left(\left(\frac{1}{l_p} + \frac{1}{u_p} \right) * Tariff_{hour} \right) \quad [5.21a]$$

$$COSTt_{s,PAL} = \sum_{ft \in FT_{PAL}} (Trucks'_{ft,s,PAL} * dpw_{ft,s} * Travelcosts_{s,NDC} * X(s, ft)) + Costs_{(un)loading,PAL} \quad [5.22a]$$

Note that these formulas are only applicable for deliveries to the NDC. For deliveries at the RDCs minor adjustments are required. For instance, not the travel costs from the supplier to the NDC is used ($Travelcosts_{s,NDC}$), but the travel costs from the supplier to the RDCs ($Travelcosts_{s,r}$). Formula [5.22a] therefore contains multiple formulas for different flow types, but is here summed to indicate the total transportation costs for transporting pallets from supplier to retailer DCs.

5.6.2 SUPPLIER TRANSPORTATION ON CARRIERS

The number of trucks required for transporting carriers (i.e.. in case of flow type 2-1a-0, 2-1a-1a or 2-0-1a, which are indicated by the subset FT_{CAR}) can be calculated in a similar way as was done for pallets with formulas [5.18a] and [5.19a]. Not the required space and capacity in cubic meters of a truck, but the number of carriers and carrier capacity of a truck are used for input. Note that the number of carriers from supplier s to a DC ($c_{ft,s}$) has already been calculated at the handling costs section. Formulas [5.18b] to [5.22b] are therefore only applicable to flow types 2-

1a-0, 2-1a-1a and 2-0-1a. Notice the similarities with formulas [5.18a] to [5.22a]. Formula [5.20] is applicable to both transportation on pallets and on carriers.

$$RS'_{ft,s,CAR} = \frac{c_{ft,s}}{dpw_{ft,s}} \quad [5.18b]$$

$$Trucks'_{ft,s,CAR} = \left\lceil \frac{RS'_{ft,s}}{CAP_c} \right\rceil + \left(\frac{RS'_{ft,s} - \left\lfloor \frac{RS'_{ft,s}}{CAP_c} \right\rfloor * CAP_c}{CAP_c} \right)^{1-k} \quad [5.19b]$$

$$Costs_{(un)loading,CAR} = \sum_{ft \in FT} (c_{ft,s} * X(s, ft)) * \left(\left(\frac{1}{l_c} + \frac{1}{u_c} \right) * Tariff_{hour} \right) \quad [5.21b]$$

$$COST_{t_s,CAR} = \sum_{ft \in FT} (Trucks'_{ft,s,CAR} * dpw_{ft,s} * Travelcosts_{s,NDC} * X(s, ft)) + Costs_{(un)loading,CAR} \quad [5.22b]$$

5.6.3 INTER-DC TRANSPORTATION

Transportation costs between the NDC and RDCs are only applicable to flow types 0-2-1a, 2-1a-1a and 2-1b-1a. Here, the number of carriers via each flow type can be used. These have already been calculated at the handling costs section.

Table 5.14: Input parameters for inter-DC transportation

Parameter	Description
$c_{IDC,o}$	Weekly number of carriers applicable to inter-DC transportation to outlet o .
CAP_c	Capacity of a trailer in number of carriers.
LF_{IDC}	Average loading factor (i.e. utilization) of an inter-DC trailer.
$Costs_{stop}$	Fixed costs per stop for docking, waiting and signing papers.

Contrary to the supplier transportation, for inter-DC transportation a fixed loading factor for trucks is used to calculate the transportation costs. As there is much data known on the loading factor of inter-DC transportation, taking an average is a good estimate. Note that this only holds when volume is sufficiently high, because otherwise the loading factor can be much lower. This needs to be checked when the model is solved. The number of carriers that need to be transported between the DCs are dependent on the decision variables. These calculations need to be linear, because we are dealing with a MILP-problem. Fixing the loading factor prevents having a non-linear relationship such as the transport inefficiency factor used in Figure 5.4. Of course, techniques like piecewise linearization can be used to overcome this problem, but here the decision has been made to keep the model as simple as possible while keeping in mind that an average is a good estimate. For inter-DC transportation the costs per stop are taken into account. It is assumed that every trip has one stop. As a truck needs to load and unload once per trip, fifteen minutes per stop is assumed for these activities. So together, stopping takes half an hour, which is then multiplied by an hourly tariff.

The term $\frac{\sum_{o \in O_r} c_{IDC}}{LF_{IDC} * CAP_c}$ calculates how many trips are needed from the NDC to RDC r . The loading inefficiency is included in the loading factor for inter-DC transport (LF_{IDC}). Inter-DC transports are carried out according to a time schedule. Usually the truck waits until it is full, except when a time limit is reached or the orders are completed. Therefore the final truck in a time block is usually not full. So the first trucks are usually full truckloads, while the final truck is a LTL. On average this leads to a loading factor smaller than 1. Say for instance there are three full truckloads of 50 carriers each and one truck with 25 carriers, on average the loading factor is 87,5%. The number of trucks (and thereby stops) is rounded up to 4. Another way to calculate this is by using the term $\frac{\sum_{o \in O_r} c_{IDC}}{LF_{IDC} * CAP_c}$. In the example there are 175 carriers, so $\frac{175}{0,875 * 50} = 4$, so the number of stops is corrected by the loading factor. Therefore rounding is not needed when an average loading factor is used.

$$Costs_{stop} = 0,5 * Tariff_{hour} \quad [5.23]$$

$$c_{IDC,o} = c_{0-2-1a,o} + c_{2-1a-1a,o} + c_{2-1b-1a,o} \quad [5.24]$$

$$COST_{t_{IDC}} = \sum_{r \in R} \left(\frac{\sum_{o \in O_r} c_{IDC}}{LF_{IDC} * CAP_c} * (Travelcosts_{NDC,r} + Costs_{stop}) \right) + (\sum_{o \in O} c_{IDC,o}) * \left(\left(\frac{1}{l_c} + \frac{1}{u_c} \right) * Tariff_{hour} \right) \quad [5.25]$$

5.6.4 OUTLET REPLENISHMENT TRANSPORTATION

Transportation costs between DCs and outlets are applicable to all flow types. Again, the number of carriers to outlets that was derived in the handling costs section can be used here. For this type of transportation a fixed loading factor is used as well. In this case this assumption is safe because all outlets will be replenished by the regional distribution centers, which is current practice. Note that when deliveries from both the NDC and the RDCs will be done (e.g. when some suppliers use flow type 0-2-0 and others 0-0-2), the loading factor might change as volume per DC decrease.

Roundtrip factor, stops and return freight

In order to ensure a sufficient loading factor (i.e. utilization of a trailer) outlets need to be combined because not all outlets have a full truckload every day. Therefore, extra kilometers will be travelled because trucks need to take a small detour. This is compensated for in the roundtrip factor (*RTF*), which adds a percentage of the kilometers to the outlets. In this way, a vehicle routing problem is avoided while still having a good estimate of transportation costs. Notice that this will not influence the flow type selection, as it is independent on the decision variables. However, in order to have a good estimate of total transportation costs and to validate the model, the roundtrip factor is included in the model.

Assuming that outlets are either supplied by a NDC or a RDC, the number of stops per outlet is fixed, provided that the volume per day for an outlet does not exceed a full truckload. There are only a few outlets that exceed this volume of a full truckload and besides, a different flow type is unlikely to increase or decrease this number significantly. Therefore, the costs for stopping at the outlets is fixed and independent of the decision variables. This only holds when outlets are either supplied by a NDC or a RDC. When they are supplied by both, the number of stops doubles. However, initially this effect will be neglected in the model by excluding stopping costs. This will make the model much easier to solve. When the model is solved and it turns out that outlets are supplied by both NDC and RDC, an extra analysis is required to see whether this would still be the optimal solution when stopping costs are added.

Outlet replenishment also has return freight from outlets, such as empty carriers and waste. The handling involved here is relatively independent on the decision variables, as these activities always have to take place. Only when the number of carriers is higher (for instance due to lower carrier utilizations), the costs for returns will also increase. As the trucks need to return to the DC to drop return freight and be ready for the next trip, the travelling costs will be incurred twice. This is different from supplier and inter-DC transportation. The latter two assume a one-way transportation and tariffs are adjusted for that. However, for outlet replenishment transportation the returns compel trucks to return to the DC. It is assumed that backhauling activities are not done.

Table 5.15: Input parameters for outlet replenishment transportation

Parameter	Description
$c_{NDC,o}$	Weekly number of carriers from the NDC to outlet o .
CAP_c	Capacity of a trailer in number of carriers.
LF_{DC}	Average loading factor (i.e. utilization) of a trailer for outlet replenishment.
$Travelcosts_{NDC,o}$	Distance-dependent costs from the NDC to outlet o , see [5.20].
$Costs_{returns}$	Costs for return freight from outlets to DCs.
RTF_{NDC}	Roundtrip factor (extra kilometers) for delivering outlets from the NDC

Formula [5.27] denotes the outlet replenishment transportation costs for each outlet from the NDC ($COSTt_{NDC,o}$). Minor adjustments need to be made for the transportation costs from the RDCs, which is applicable to all other flow types that are not indicated in formula [5.26]. The outlet replenishment transportation costs from RDC r to outlet o is denoted by $COSTt_{r,o}$.

$$c_{NDC,o} = c_{0-2-0,o} + c_{2-1a-0,o} + c_{2-1b-0,o} \quad [5.26]$$

$$COSTt_{NDC,o} = \frac{c_{NDC,o}}{LF_{DC} * CAP_c} * (Costs_{returns} + 2 * Travelcosts_{NDC,o} * RTF_{NDC}) + c_{NDC,o} * \left(\left(\frac{1}{l_c} + \frac{1}{u_c} \right) * Tariff_{hour} \right) \quad [5.27]$$

The total costs for transport are denoted in formula [5.28].

$$COSTt = \sum_{s \in S} (COSTt_{s,PAL} + COSTt_{s,PAL}) + COSTt_{IDC} + \sum_{o \in O} COSTt_{NDC,o} + \sum_{r \in R} \sum_{o \in O_r} COSTt_{r,o} \quad [5.28]$$

5.7 WASTE

First of all it is important to know the most critical assortment for which waste is a problem. Approximately 50% of the volume in the fresh assortment is private label. For these items there is no difference in waste among different flow types because suppliers cannot sell these products to other customers anyway. As waste is less of an issue for products having a remaining shelf life of more than 10 days, only the products that have a shorter remaining shelf life and that have no private label qualify for a further analysis on waste. This is approximately 25% of the volume in the fresh assortment, which reduces the group of worrisome products significantly. Nevertheless, these are typically the products that have the highest shares in waste as well.

According to Van Donselaar & Broekmeulen (2012), waste is dependent on product life (i.e. remaining shelf life), mean demand, variance, lead time, review period, case pack size and fill rate. Most of these parameters are fixed in reality, such as mean demand and variance. The lead time, review period, case pack size and fill rate is also assumed to be fixed in this model, which is explained in the conceptual model. The only variable that can be influenced by the flow type selection is the remaining shelf life. However, given the limited set of flow types identified in Table 4.2, the differences in remaining shelf life between each of these flow types is very small as there is only one stock point in each flow type. Cycle stock is equal in every flow type considered in this study. The only difference is in minimum order quantities and safety stock because of imbalance when keeping inventory more downstream in the supply chain. Due to the pooling effect it is expected that the safety stock for the 'stockless for retailer'-flow types is lower compared to the 'stockless for supplier'-flow types. This might favor the former flow types in terms of waste, especially compared to delivery at RDCs directly after production (i.e. flow type 0-0-2).

Van Donselaar (1990) studied the impact of imbalance with integral stock norms in divergent systems with lot-sizes. The problem is similar to what we have here. Due to unknown demand, goods might be at the wrong location when it is pushed downstream in the system (i.e. 'stockless for supplier'-flow types). This might lead to lower service levels, which requires more safety stock at the downstream points in the system. This in turn can cause extra waste. However, Van Donselaar (1990) showed that the impact of imbalance on service level is small for most systems. Only for systems with large production batch sizes (or minimum order quantities) having a central depot (e.g. by keeping stock at the supplier) is beneficial. This is not common for the fresh assortment because of its perishability, so frequent replenishments will be done in order to prevent waste. Therefore, the effect of imbalances in the system is limited. Van der Vlist (2007) also argues that service levels will increase by pushing the inventory downstream, despite the possible imbalances that might occur.

Nevertheless, when shifting assortment from the NDC to the RDCs, it is expected that waste will increase due to the imbalance effect. This section provides a quick analysis on typical slow-moving highly perishable items. First of all, it should be noted that perishables compared to the ambient assortment, are relatively fast-moving. Less than 400 items at the temperature-controlled NDC have a demand of less than 50 case packs per week. Of those 400 items, about 10% have a remaining shelf life of 10 days or less. So the number of items at the temperature-controlled NDC that are risky in terms of waste, is very limited. Especially when it is compared to the ambient NDC, where more than 4000 items have a demand of less than 50 case packs per week. For those 400 items currently held at the NDC, the effect on waste when keeping those at the RDCs is expected to be minimal. Simulations with the tool developed by Van Donselaar & Broekmeulen (2012) showed that the expected extra waste in the RDCs is always below 6%, as shown in Figure 5.5. The upper line shows the extra waste when shifting slow-moving items from the NDC to the RDCs, with a remaining shelf life of 3 days for the DC (time allowed at DC).

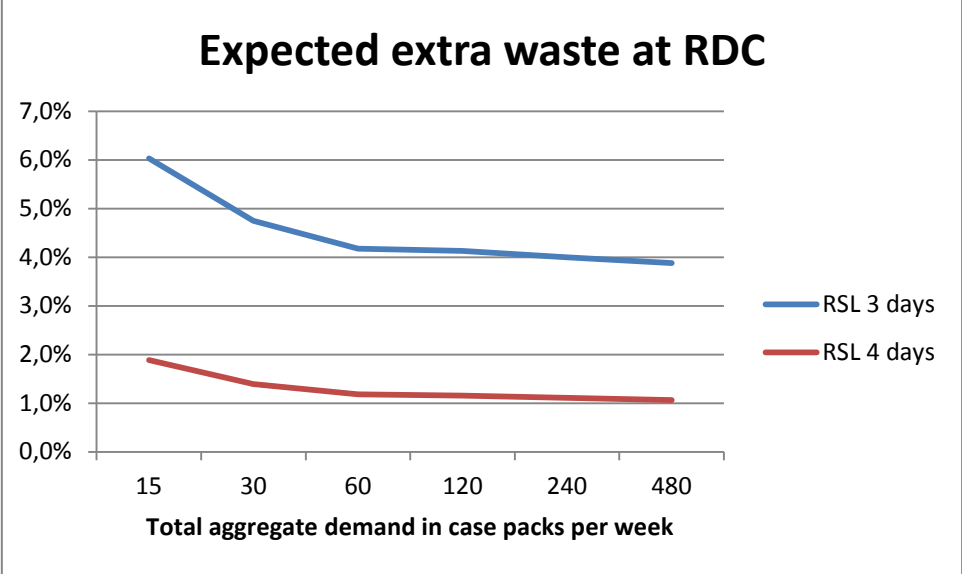


Figure 5.5: Expected extra waste when shifting slow-movers from NDC to RDCs

Waste increases because volume is split over four RDCs. Due to the pooling effect, the total aggregate safety stocks at the RDCs are higher than the required safety stock when inventory is kept at the NDC. When volume is split over three RDCs, the extra waste illustrated in Figure 5.5 does not exceed 2,5%.

From this short analysis it can be concluded that waste is only an issue for a very limited number of items and suppliers. The extra safety stock that is required is unlikely to differ a lot between the flow types considered, due to frequent production batches and frequent replenishment. Even for the very limited number of items where waste is an issue, the extra waste costs are very low. The costs for waste are therefore neglected. Even though waste costs are not likely to increase significantly, the functional requirement of maintaining freshness might be violated. Therefore, when interpreting the results it should be considered that for some slow-moving highly perishable items with high variability, measures are required in order to prevent this violation. For instance to either place the inventory at the supplier or the NDC, rather than at the RDCs.

6 MODEL SOLVING

In this chapter the model is solved and results are discussed. Thereby answering research question 5: *What are the advantages and disadvantages of the different distribution flow types and what factors are most influential on the distribution flow type selection?* It starts by validating the model, by which it is shown that the model is able to represent reality. Then, a comparison between flow types is made using fictitious suppliers. This section will illustrate the differences between flow types based on sales volume. Next, a sensitivity analysis is performed in order to see what happens when input parameters change. Furthermore, a scenario analysis is performed to investigate the impact of future changes in the network structure on the flow type selection and on costs. Finally, a discussion about the results is provided in section 6.6.

6.1 MODEL VALIDATION

A model is a simplified representation of a real system and can therefore never be exactly correct. However, a model is useful for study when accuracy is sufficient. Throughout the process of developing this model, qualitative and quantitative validations have been performed. Initially, qualitative methods such as interviews were used to build this model. Also, input data from several departments was retrieved and checked for inconsistencies. Once the initial formulas were derived, the outcomes were checked with actual data. One issue that arises is that it is unclear what causes a deviation. It can either be the cost driver or the base cost that is incorrect. Therefore not only total costs, but also a number of cost drivers were checked. Based on these comparisons, some of the formulas as described in the previous chapter were improved such that they were more consistent with reality.

6.1.1 VALIDATION OF CURRENT FLOW TYPES

Table 4.2 shows the set of possible flow types that were identified in the conceptual model. In reality, the flow types are slightly different. Currently four flow types are used and are listed in the table below (Table 6.1). The quantitative validation is based on these four flow types.

Table 6.1: current flow types

Current flow types
2-2-1a
2-0-2
2-0-XD (pure cross-dock)
2-0-TR (pure transito)

Figure 6.1 shows the relative difference between the model and actual key figures such as number of boxes, carriers, pallets, kilometers, trips, duration per trip and costs. Note that the model is approximately 2% below the actual figures for most parameters, which can be explained by the fact that the model only incorporates the top 100 suppliers, which are responsible for about 98% of total volume.

6.1.1 PARTIAL VALIDATION

As the boundaries of the model extend the boundaries of the company, it was not possible to validate all parts of the model. Only the key figures and costs for Jumbo could be compared with the model. Unfortunately the costs for suppliers cannot be validated. Nevertheless, many activities are comparable to the activities that take place at the retailer, such as picking on store level or loading a carrier. Also, as the number of pallets and carriers are validated for Jumbo, these cost drivers are for a great extent also applicable to the suppliers. This indicates that this model is quite accurate, not only for Jumbo but also for suppliers. However, extra attention needs to be paid to this issue, for instance by performing a more extensive sensitivity analysis when interpreting the results.

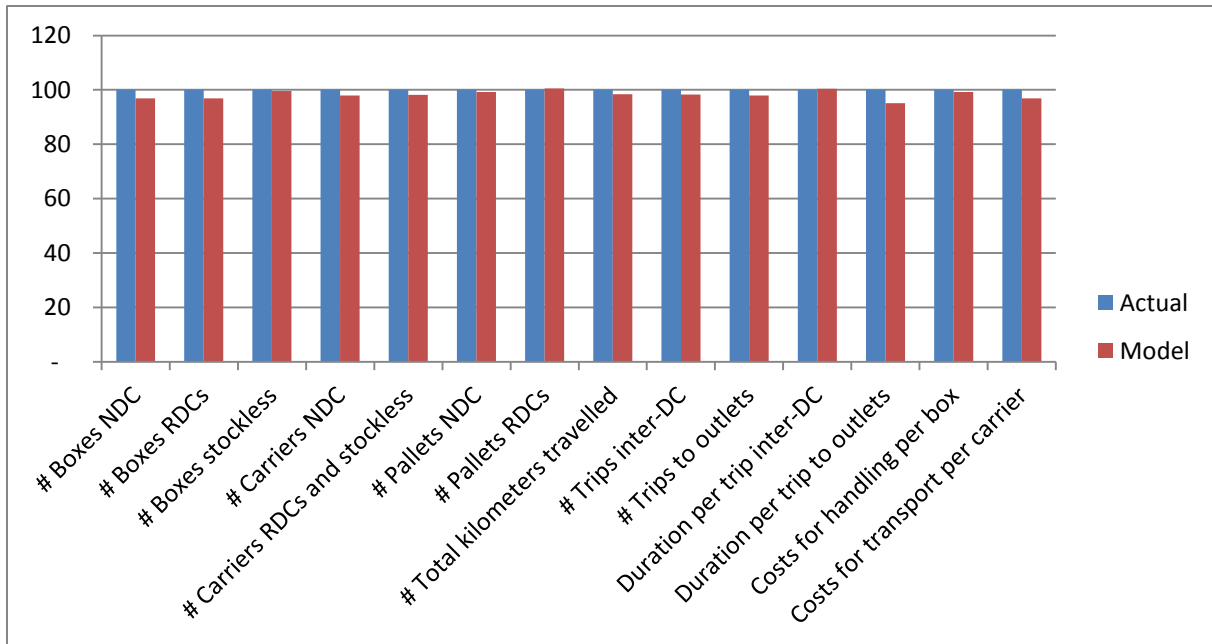


Figure 6.1: Relative difference between the model and actual key figures for model validation

6.2 FLOW TYPE COMPARISONS

This section illustrates the differences between flow types by varying input parameters such as sales volumes per supplier, number of items, lead time, production batch sizes etcetera. It shows how flow types are distinct from each other by comparing a base model with other scenarios. The original model is designed to choose the best flow type for each individual supplier, taking into account the flow type decisions of other suppliers.

For this analysis fictitious suppliers are used and it is assumed that they are exactly the same except for their sales volume. On the horizontal axis of the following graphs there are 100 fictitious suppliers having an increasing sales volume. In order to show the differences between flow types, it is assumed all fictitious suppliers choose the same flow type, while in the actual model the decision can be different among suppliers. The characteristics of the fictitious suppliers of the base model are listed here. All suppliers have:

- 30 stock keeping units (SKUs)
- Varying total sales volumes, evenly split over the SKUs
- 3 production batches per week
- 6 deliveries per week for 'stockless for supplier'-flow types
- 12 deliveries per week for 'stockless for retailer'-flow types
- A net capacity of a carrier (NCC) of $0,58m^3$

6.2.1 BASE MODEL

The graph for the base scenario shows that the 'stockless for supplier'-flow types (0-2-0 and 0-0-2) have the lowest costs. When volume is higher, the costs for pick-to-zero at the RDCs (2-0-1b) decrease and are approaching the 'stockless for supplier'-flow type costs. This is mainly due to the handling costs. Table 5.10 already showed that the handling costs for storing and replenishing pallets are present for the 'stockless for supplier'-flow types, while in a pick-to-zero operation only replenishment is required. On the other hand, more frequent deliveries and half-full pallets are delivered when using pick-to-zero. This drawback of pick-to-zero is not so much of a problem anymore when volume is high. Nevertheless, keeping stock at the retailer is still less expensive even when volumes are high. Besides, one could argue whether or not storing is needed when volume is very high. Suppose fifteen pallets bananas arrive at a RDC, it is perhaps unlikely that none of these pallets have to be stored before being replenished at the order picking floor. The costs for XD-TR flow types (i.e. 2-1a-0 and 2-0-1a) are quite high compared to other flow types. This is due to the relatively low net capacity of a carrier and the number of

SKUs is not very high, such that delivering via ‘stockless for supplier’-flow types is usually less expensive.

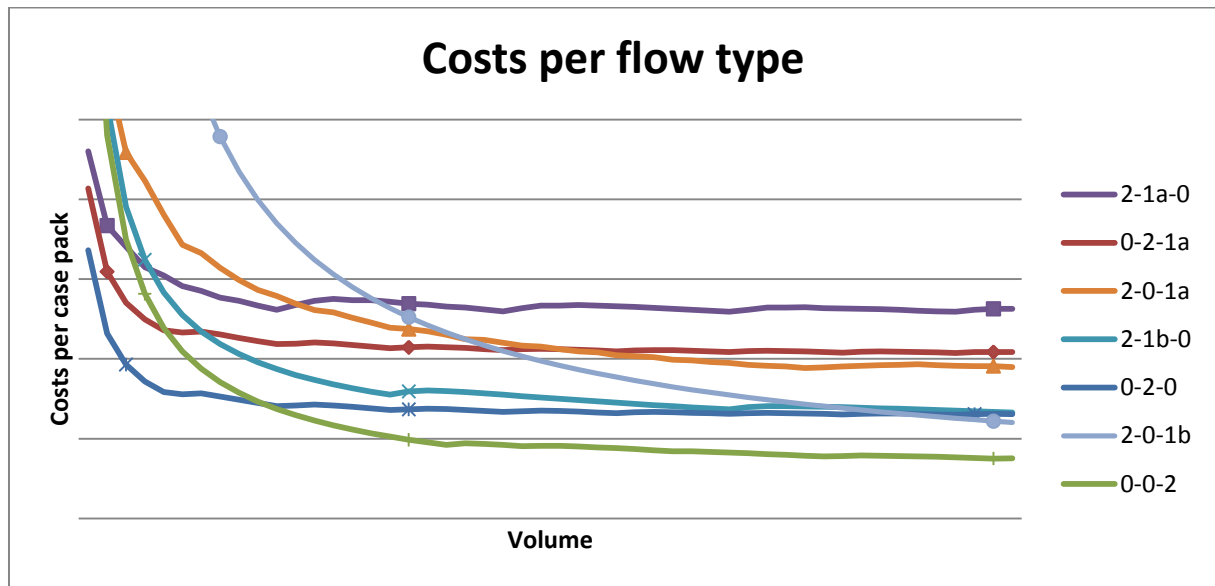


Figure 6.2: Base scenario

6.2.2 TRADE-OFF BETWEEN NDC AND RDC

From the graph in the base scenario it can already be seen that NDC-flow types (such as 0-2-0 and 2-1a-0) are in favor of their RDC-counterparts when volume is low. The examples in the next graph show that at some point the RDC-flow types become favorable. This is a result that can be expected, because when volume is low, the utilization of pallets is usually also low. This means more transport and handling, especially the latter, from supplier to DC. When there is only one DC to deliver to, the critical mass will sooner be reached. However, when volume is sufficient, full pallets will also go to the RDCs. At that point, RDCs become more favorable due to the lower transportation costs to outlets. Figure 6.3 shows an example for two pairs of flow types. It can be seen that when volume increases, at some point RDC deliveries become more favorable.

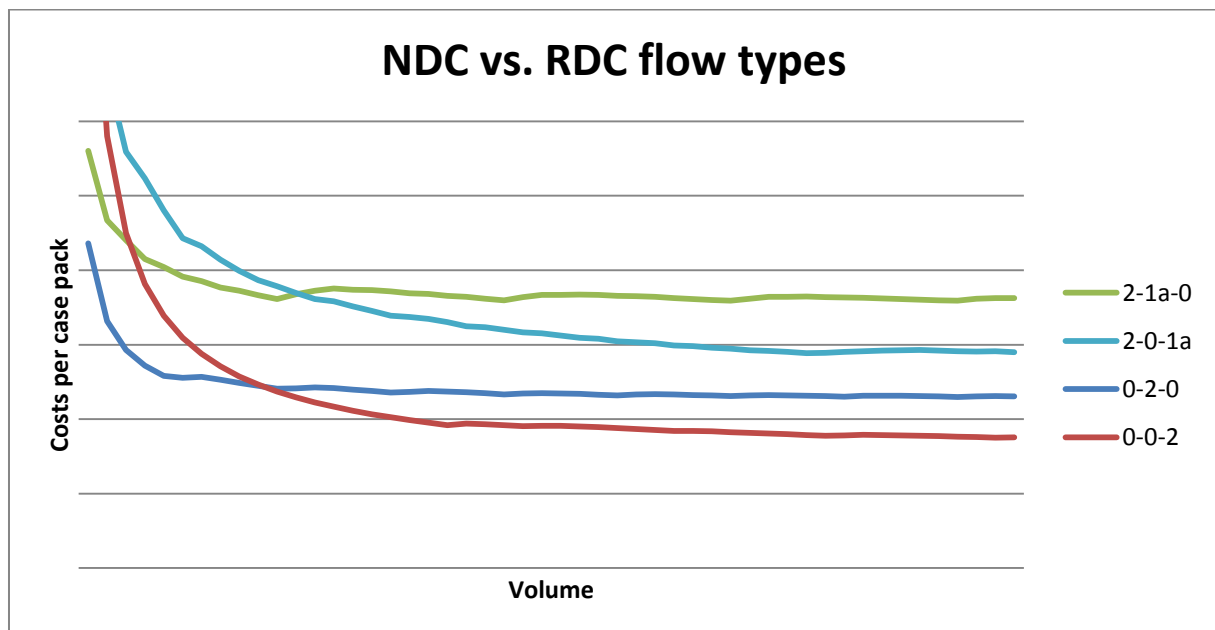


Figure 6.3: NDC vs. RDC flow types

6.2.3 INTER-DC FLOW TYPES

Flow types that consolidate freight from the NDC at the RDCs (like 0-2-1a, 2-1a-1a and 2-1b-1a) are always more expensive than their direct delivery counterparts (0-2-0, 2-1a-0 and 2-1b-0 respectively). The sum of inter-DC and outlet replenishment trucking costs for the RDCs are approximately equal to the trucking costs for direct delivery to the outlets from the NDC. The extra handling at the RDCs make the consolidated flow types more expensive. This can be explained by the relative short distances in the Netherlands, which make a consolidation operation usually more expensive than direct delivery.

However, it should be said that there are at least two important assumptions that might not hold when there are deliveries from both NDC and RDCs to outlets. First, truck utilization is likely to be lower when volume is split. Second, more stops at the outlets will be made, which is not included in the model. Therefore the disadvantage of inter-DC flow types compared to their direct delivery counterparts is less significant than Figure 6.4 implies. In the current situation shipments from the NDC are consolidated at the RDC (comparable to flow type 0-2-1a), rather than sending it directly to the outlets from the NDC (comparable to flow type 0-2-0). Volume from the NDC is currently insufficient to make direct delivery cost efficient.

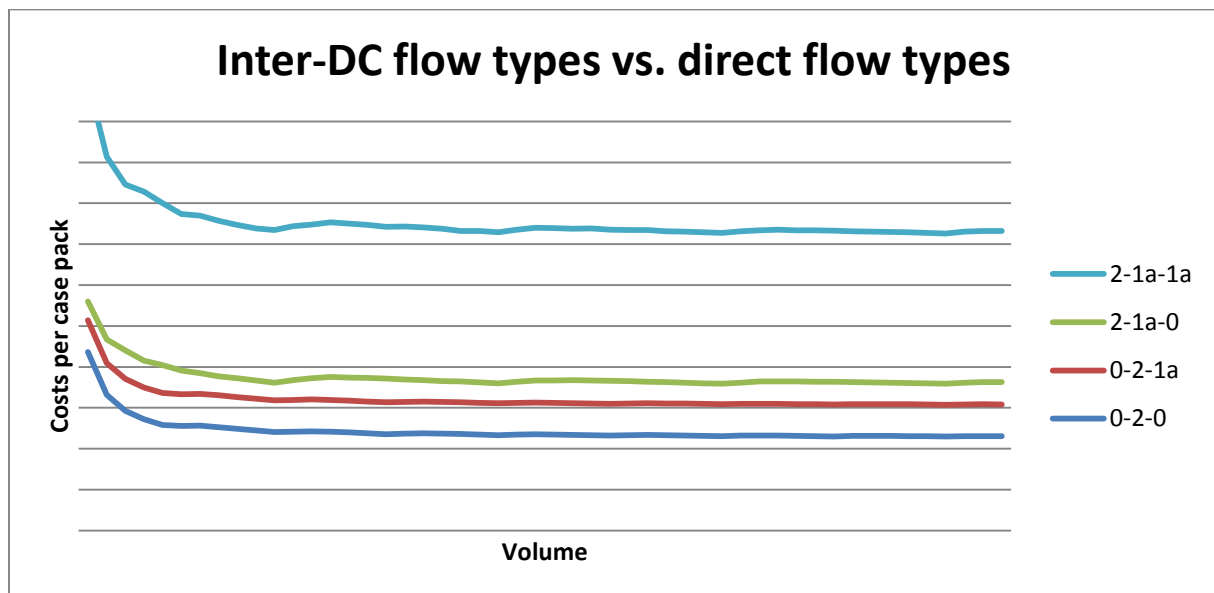


Figure 6.4: Inter-DC flow types vs. direct flow types

6.2.4 CROSS-DOCK AND TRANSITO VERSUS PURE CROSS-DOCK

Current practice is to either cross-dock (XD) or apply transito (TR) for a supplier. This study has proposed a hybrid form of that (XD-TR), which is referred to as flow type 2-1a-0 (at NDC) or 2-0-1a (at RDCs). The following graph shows that this combination always outperforms pure cross-docking. This is mainly due to the higher utilization of carriers when combining the two practices. This results in fewer carriers in total, which has strong effects on both handling and transportation costs. So despite the extra handling costs of stacking boxes when applying transito, having fewer carriers to transport and handle makes the combination less expensive. It is also expected that XD-TR will outperform pure transito, as currently every outlet gets its own carrier when arriving at the RDCs. In the hybrid form, these carriers can be combined because a carrier does not necessarily have to be outlet-specific. Besides, for some outlets stacking will not be necessary, such that these carriers can be moved immediately from one truck into another (XD).

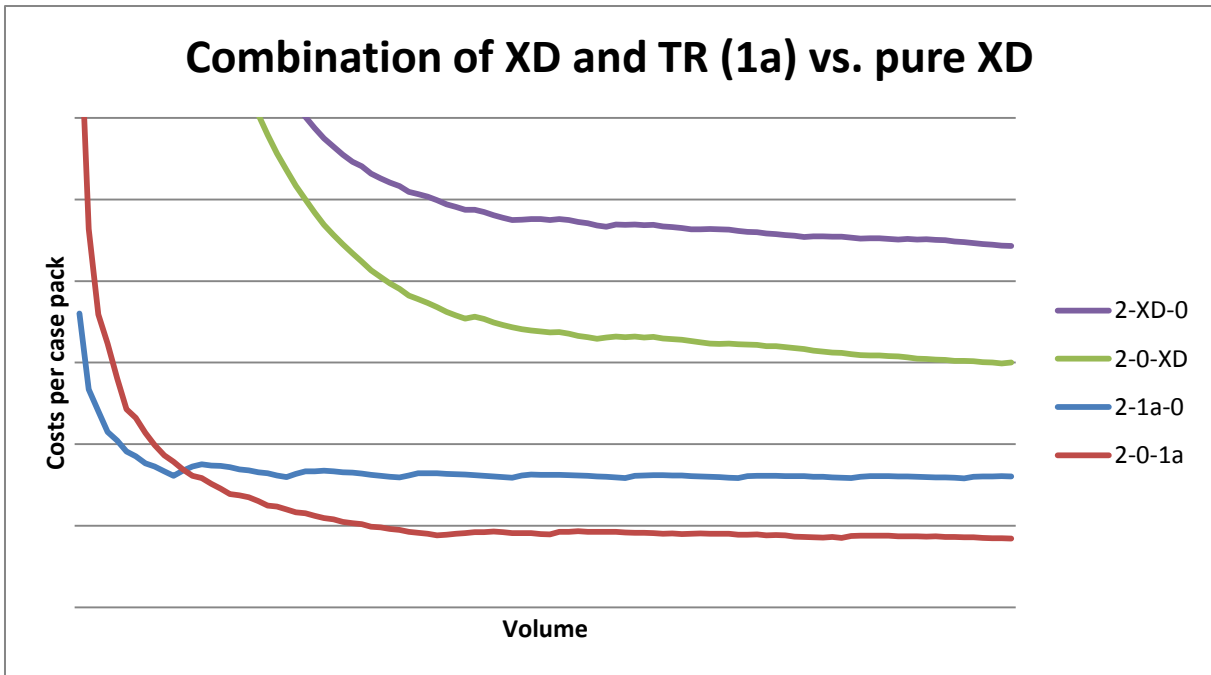


Figure 6.5: Pure cross-dock flow types

6.2.5 CROSS-DOCK AND TRANSITO WITH HIGHER CARRIER CAPACITY

The net capacity of a carrier (*NCC*) is based on the current practice where cross-docking and transito is split. In the hybrid form, one would expect a higher utilization of carriers. Therefore an experiment was done with a higher capacity of a carrier, so the capacity of a carrier was set at its physical maximum of 0,77m³. The following graph shows that other flow types usually outperform the cross-dock/transito-flow types at their original and increased carrier capacities. However, when carrier capacity is increased, the difference is smaller. This might make XD-TR flow types favorable for some suppliers, depending on other supplier characteristics.

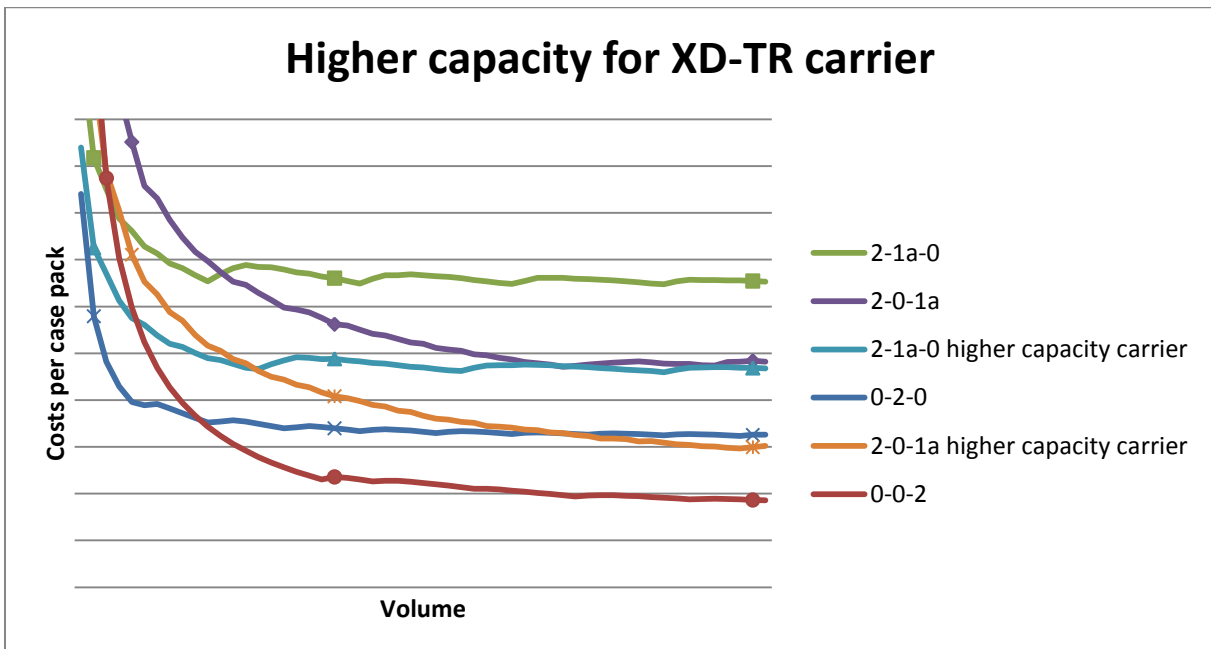


Figure 6.6: Increased capacity NCC

6.2.6 CROSS-DOCK AND TRANSITO WITH MORE SKUs

The main advantage of cross-dock/transito-flow types is that the number of SKUs is relatively independent on the costs. In case of stock-keeping flow types or pick-to-zero, more pallets need to be handled and transported as well, whereas for cross-docking and transito the number of carriers remains the same, regardless of how many SKUs there are on a carrier. The following graph shows this effect of more SKUs (from 30 to 150 SKUs), which makes 0-0-2 and 2-0-1b more expensive while the costs for 2-1a-0 and 2-0-1a are equal to when there were fewer SKUs. This makes suppliers with medium to high sales volumes, many SKUs and an alternating assortment interesting candidates for a combination of cross-dock and transito.

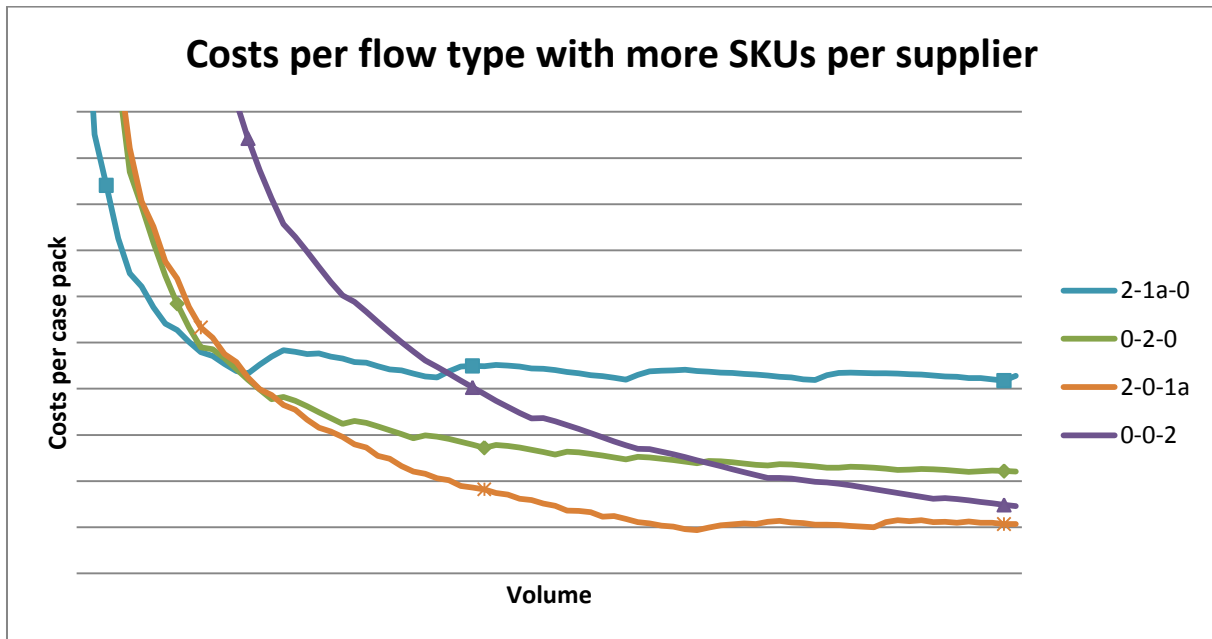


Figure 6.7: More SKUs per supplier

6.2.7 INCREASING LEAD TIME

'Stockless-for-retailer'-flow types are usually not interesting for low volumes due to low utilization of pallets, carriers and trucks, which is a result of delivering twice a day. When this can be reduced to only once a day, the utilization increases and these flow types become interesting at lower volumes. Note that in order to do so, the lead time for some outlets needs to be increased. The outlets that get delivered in the late afternoon (the second shift) need to order approximately 36 hours in advance, instead of the original 24 hours. Not surprisingly, Figure 6.8 shows that the 'stockless-for-retailer'-flow types then becomes more attractive, although some effects are not in the model. Obviously the increased lead time has an impact on the required safety stocks in outlets in order to keep service levels high. In turn, this might lead to extra waste in outlets.

6.2.8 MORE BATCHES PER WEEK

When the number of production batches per week is increased from 3 to 6, flow types 0-2-0 and 0-0-2 are more and more like the traditional flow types 2-2-0 and 2-0-2 respectively (see Appendix A). This makes the 'stockless-for-supplier'-flow types more expensive due to lower utilization of pallets (i.e. increasing the number of pallets to be handled). This mainly has an effect on the handling part from supplier to DC, while the costs from DC to outlet remain the same. This effect is only present at low volumes. At higher volumes, the utilizations are already quite high such that the difference becomes negligible.

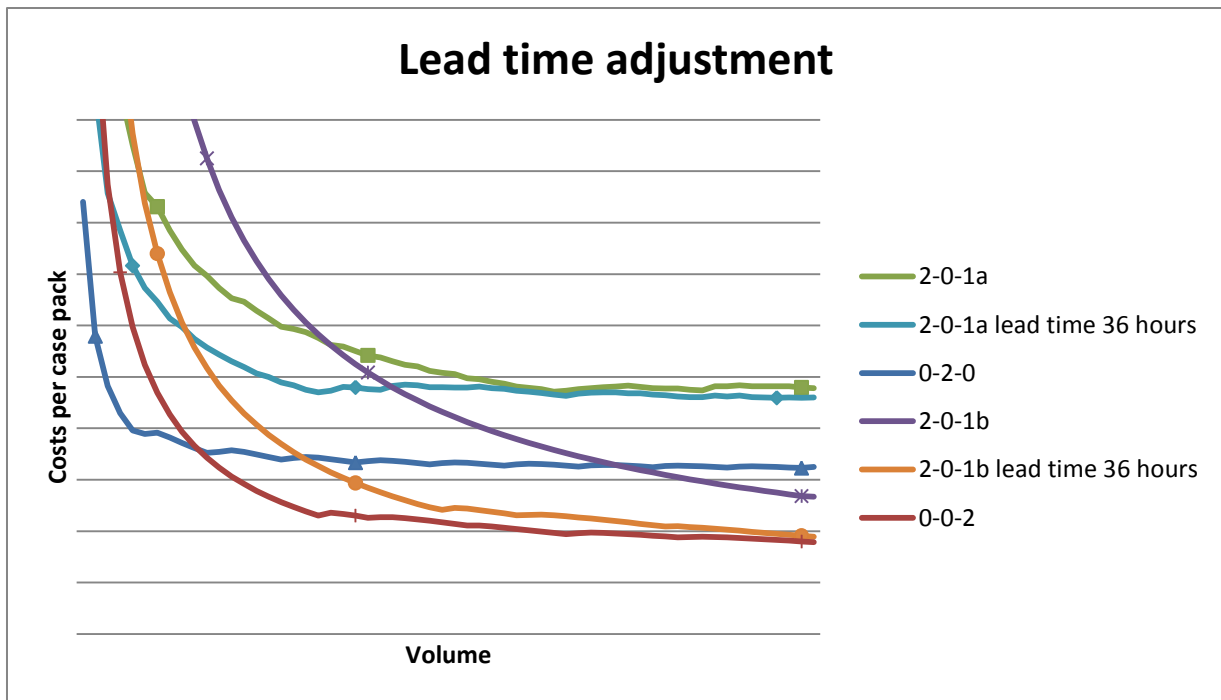


Figure 6.8: Lead time to 36 hours (one delivery per day)

6.2.9 INTERMEDIATE CONCLUSIONS

- 'Stockless for supplier'-flow types (such as 0-2-0 and 0-0-2) are less costly than their traditional counterparts (2-2-0 and 2-0-2) because shipments are more homogeneous, which is illustrated in Appendix A. Furthermore, Figure 6.2 showed these flow types are usually more cost efficient than 'stockless for retailer'-flow types. Especially when the number of SKUs is relatively low and there are few deliveries, which is very advantageous for the utilization of pallets and trucks. Besides, the base costs are lower compared to for instance the hybrid flow type of cross-dock and transito. The latter flow type usually has more costs for handling boxes as boxes are handled both at the supplier and at the retailer.
- Put-to-zero becomes interesting when volume increases. However, in that case pick-to-zero is more realistic, as explained in section 5.5. This means that extra costs will be made for replenishing pallets, which makes pick-to-zero only interesting when volume increases even more in which case also storing activities might be required. Also, put/pick-to-zero becomes very expensive when the number of SKUs increases. As Jumbo has many SKUs, this is disadvantageous for this flow type. Therefore, put/pick-to-zero most often underperforms 'stockless for supplier'-flow types.
- Figure 6.3 illustrates the break-even points for NDC versus RDC deliveries. Note that delivering via both (without consolidation at the RDC) requires a sufficient volume for both as otherwise the loading factor (truck utilization) will decrease. Besides, delivering via both NDC and RDC doubles the number of stops at outlets.
- Consolidation at the RDC (inter-DC transportation) is quite expensive. Especially in combination with cross-dock/transito or put/pick-to-zero (e.g. flow types 2-1a-1a and 2-1b-1a). For these flow types the utilization of carriers is already quite low and by adding more activities the handling costs will increase even more.
- On average XD-TR is usually more expensive than 'stockless for supplier'-flow types. However, for some suppliers this flow type might still be beneficial. Especially when the number of SKUs is high, which makes 'stockless for supplier'-flow types more expensive. Also, it is expected that the net capacity of a carrier (*NCC*) can be increased because of the higher utilization of carriers when applying a combination of cross-dock and transito. Furthermore, when the lead time can be increased, thereby decreasing the number of deliveries for XD-TR, this flow type becomes even more favorable.

6.3 RESULTS

The previous section illustrated the relative differences among flow types with fictitious suppliers. In this section real suppliers and their actual input data were used. The model was solved on an Intel®Core™i7 machine with 2,4 GHz and 8 GB RAM memory in AIMMS as this allowed to use the CPLEX 12.6 solver. Only the top-100 suppliers were included in the model, as they are responsible for approximately 98% of total volume. The model was solved very quickly, within one second for all runs. It turns out that the binary constraint [C.2], which requires that the main decision variables $X(s, ft)$ are binary, can be relaxed to a non-negative constraint. In other words, the non-integer solutions for decision variables $X(s, ft)$ are already integers. Therefore, only four binary decision variables are left (related to Y_{ft}). This makes the model almost similar to a LP-problem and makes it much quicker to solve, as the non-integer model needs to be solved at most $2^4 = 16$ times.

The model is solved given the current network of four RDCs and one NDC, but without DC capacity restrictions. The results show only the flow types that are chosen by the model (see *base model* in Figure 6.2 for the exact numbers). For most suppliers the ‘stockless for supplier’-flow type at the RDC (i.e. 0-0-2) is the best flow type. Note that the model chooses to deliver via the RDCs and not via the NDC. It turns out that the utilization of carriers has a very big impact on costs because this determines how many carriers are handled and transported. Using both NDC and RDCs lowers the utilization of carriers as volume is split, which results in more ‘remaining’ carriers that are not full. Therefore the model is inclined to either use the NDC or the RDCs, but not both. So for all suppliers the model chooses to use the RDC instead of the NDC, mainly due to the lower transportation costs to outlets. Note that a limitation of the model is that it does not include fixed facility and inventory costs, which are likely to be higher when using only RDCs instead of using a NDC.

Table 6.2 shows that in a few instances, when XD-TR costs are lower compared to ‘stockless for supplier’-flow types, the model chooses flow type 2-1a-1a for a few suppliers. These are suppliers that have a low sales volume, such that delivering at a NDC is more cost efficient than delivering at the RDCs. Note that the model assumes a fixed loading factor for inter-DC transportation, which will not be met with these low volumes. Besides, it is not worthwhile to set up such an operation for only a few suppliers as we also want to limit the number of flow types being used.

The latter argument can also be used to exclude put/pick-to-zero from further analysis. This flow type is only beneficial when the sales volume per item is very high, e.g. for suppliers that deliver only a few products with high sales volumes. Besides, in the intermediate conclusion in section 6.2.9 the costly PTZ-operation has already been questioned. Now it is shown that the model is also reluctant to choose this flow type.

6.4 SENSITIVITY ANALYSIS

As was discussed in section 6.1.1, the model is partially validated. In order to see what the results would be when some of the input parameters were different, a sensitivity analysis was performed. The model, including actual data of real suppliers, is solved with varying input parameters which can be found in Table 6.2.

The input parameters that varied were the base costs for handling, transport costs, loading inefficiency of pallets (*LIF*) and the net capacity of carriers (*NCC*). For the handling base costs a split is made to highlight the differences among flow types. For instance base costs S1 and S2 are mainly applicable to flow types 0-2-0, 0-2-1a and 0-0-2, which are indicated as ‘stock’, since these flow types keep stock at the retailer DC. Other flow types are indicated by XD-TR (e.g. 2-0-1a) or PTZ (e.g. 2-0-1b). Table 6.2 shows the results are quite sensitive to the handling base costs. For instance, when base costs S3 and S4 (related to XD-TR) increase by 25%, the number of suppliers via XD-TR decrease from 8 in the base model to only 3. However, these shifts are predictable and it is mainly a trade-off between 0-0-2 (stock) and 2-0-1a (XD-TR). When the base costs for one flow type increase, the other becomes more attractive and more suppliers should deliver via this flow type. Changing PTZ costs has a minor impact on the outcome.

Increasing or decreasing transportation costs (tariffs) has no effect on the results. Obviously transportation costs will increase or decrease, but in total this will not change the flow type selection of suppliers. This can be explained because for all flow types transport is required and the relative difference among flow types in transport is rather low. On the other hand, the loading inefficiency factor (*LIF*) which is estimated to be 20%, does influence the flow type selection when this number increases. Pallet transportation becomes more expensive when this factor increases, such that XD-TR becomes more attractive.

As explained in Appendix A, the advantage of 'stockless-for-retailer'-flow types over the traditional supply chain is not only its freshness, but also the decreased handling costs. As it cannot be expected that all suppliers will be able to deliver via a flow type such as 0-0-2, the model is also solved for when the number of production batches is equal to the number of deliveries per week, making it similar to a traditional supply chain. It is not surprising that in this case more suppliers deliver via 2-0-1a, due to the extra costs made at flow type 0-0-2.

Finally, Appendix C describes an alternative method (alternative 1) to estimate the required number of pallets. Appendix C shows that when using this alternative method, the number of incoming pallets at the RDCs is overestimated. For that reason flow type 0-0-2 is less cost efficient when using this method, which doubles the number of suppliers that deliver via XD-TR.

Table 6.2: Results of sensitivity analysis with varying input parameters

Input parameter	Associated flow type set	Value	Number of suppliers per flow type			
			0-0-2 (stock)	2-1a-1a (XD-TR)	2-0-1a (XD-TR)	2-0-1b (PTZ)
Base model	All	100%	91		8	1
S1 and S2	Stock	75%	92		8	
		125%	86		13	1
S3 and S4	XD-TR	75%	74	2	23	1
		125%	96		3	1
S2 and S5	PTZ	75%	91		8	1
		125%	90		10	
R1 - R4	Stock	75%	99		1	
		125%	67	2	26	5
R5 - R7	XD-TR	75%	82	2	15	1
		125%	92		7	1
R1, R4 and R8	PTZ	75%	91		8	1
		125%	90		10	
Tariff_{hour} (supplier)	All	80%	90		9	1
Tariff_{KM} (supplier)	All	120%	91		8	1
Tariff_{hour} (outlet)	All	80%	91		8	1
Tariff_{KM} (outlet)	All	120%	91		8	1
LIF	Stock and PTZ	1,0	91		8	1
		1,4	88		11	1
		1,6	86		13	1
NCC	XD-TR	117%	83		16	1
		133%	80		19	1
BPW_s	Stock	DPW _s	84		15	1
Method for # pallets	Stock and PTZ	Alternative 1	80	3	16	1

Results when NDC is used

As explained before, the model chooses to either use the NDC or the RDCs. To gain supplier-specific insights it is also interesting to see which suppliers would choose for flow type 0-2-1a when the model is forced to use the NDC for at least one supplier. This is relevant for the current situation as there are also items kept on stock at the NDC. These products are picked at the NDC and shipped to the RDCs for consolidation. The next paragraph explains which suppliers choose for either flow type 0-2-1a or 2-0-1a.

Supplier-specific insights

It can be seen that for some experiments there are more suppliers delivering via XD-TR than was the case in the base model. Now it is interesting to see which suppliers qualify for XD-TR and which for keeping stock at the NDC and RDCs. In the base model, more suppliers deliver their goods on pallets to the RDCs. The characteristics of the suppliers that are eligible to switch from 0-0-2 to either 2-0-1a or 0-2-1a can be best explained by the following ratio [6.1]:

$$p_{0-2-0,s} = \sum_{i \in I} \left(\frac{\sum_{o \in O} b_{i,s,o}}{b p p_{i,s} * b p w_s} + 0,5 \right) * b p w_s \quad [5.1]$$
$$Ratio_s = p_{0-2-0,s} / \sum_{i \in I} \frac{\sum_{o \in O} b_{i,s,o}}{b p p_{i,s}} \quad [6.1]$$

Recall formula [5.1], which calculates the number of pallets required to the NDC. There is an equivalent formula for the RDCs. The ratio [6.1] shows the relative increase in number of pallets due to rounding. When there are many items to be delivered per delivery moment, more pallets are required. Especially when volumes are low, the +0,5 factor in formula [5.1] plays an important role by increasing the required number of pallets. This effect is even stronger at the RDCs, because the volume is split over four RDCs. Suppliers with a high $Ratio_s$ are the first candidates to switch from 0-0-2 to either 2-0-1a or 0-2-1a. Suppliers with a high $Ratio_s$ typically have many items, low sales volumes per item, many batches per week or a combination of these factors.

Suppliers that are currently delivering via either transito or cross-dock are also inclined to use the hybrid flow type XD-TR. This can be explained because for most of these suppliers the number of case packs per box is greater than one, already in the current situation. As these suppliers pick on outlet-level, they are allowed to put multiple SKUs in a box, such that fewer boxes than case packs have to be handled at the RDC. This makes XD-TR an interesting flow type, especially for suppliers delivering many slow moving SKUs. Another observation is that the suppliers choosing XD-TR usually have high values for m^3 per box, meaning that relatively fewer boxes need to be handled which makes XD-TR relatively less expensive compared to keeping stock at the RDC. By this we learn that when a supplier delivers via XD-TR, it should strive to have big boxes in order to decrease the handling costs at the distribution center of the retailer.

Suppliers having low sales volumes are inclined to switch from 0-0-2 to 0-2-1a, as the critical mass for full pallets is reached sooner when delivering to a NDC instead of four RDCs. This effect has already been shown in section 6.2.2. So typically suppliers having many small boxes (e.g. suppliers of convenience products) are keener to supply via the NDC rather than XD-TR.

Smaller suppliers

As explained in section 6.3, only the top 100 suppliers are included in the model. The remaining suppliers, responsible for approximately 2% of sales volume, are usually suppliers with very few SKUs. Most often they supply 'weeks-fresh' or 'less perishable' products. Therefore the average number of production batches per week is lower compared to the top 100 suppliers. Based on these characteristics it can be concluded that the most cost efficient flow type for these suppliers is either 0-0-2 or 0-2-1a. When the $Ratio_s$ is rather high for delivering at the RDC, these suppliers are best supplied via the NDC. Besides, volumes are quite low such that transportation to four RDCs is expensive. Therefore, most of these suppliers will deliver at the NDC, although for some the RDC is still a good option. This depends on their sales volume per SKU and location.

6.5 SCENARIO ANALYSIS

The goal of this section is to investigate the effect of network changes on flow type selection and costs. The results in the previous sections have shown that XD-TR and 'stockless for supplier'-flow types are the most cost efficient flow types. This sections starts with two realistic scenarios (A and B), based on the current network. Scenarios C, D and E discuss three possible future networks. In section 6.5.2 the scenarios are compared.

6.5.1 SCENARIO DESCRIPTIONS

Current scenario A: four regional and one national distribution center with capacity constraints

The results in the previous section showed that it is mainly a trade-off between the regional 'stockless for supplier'-flow type (0-0-2) and the XD-TR solution (2-0-1a). However, the model described there is a model without capacity restrictions. Therefore the model was also solved including the following constraints:

$$\sum_{i \in I} \sum_{s \in S} \sum_{o \in O} cp_{i,s,o} * X(s, 0 - 2 - 1a) \leq Capacity_{NDC} \quad [C.4]$$

$$\sum_{i \in I} \sum_{s \in S} \sum_{o \in O_r} cp_{i,s,o} * X(s, 0 - 0 - 2) \leq Capacity_r \quad \forall r \in R \quad [C.5]$$

Where $Capacity_{NDC}$ and $Capacity_r$ denote the capacity in number of case packs of the NDC and the RDCs respectively, which are based on the actual capacities of the current distribution centers. In the current situation the capacity of the NDC is required in order to deliver to outlets. It is used for a limited assortment, mainly slow moving and highly perishable items to benefit from the pooling effect and to decrease the total number of picking locations in the network. Because the volume is insufficient to make direct delivery from the NDC to outlets profitable, it is consolidated at the RDC. The utilization of trucks would be very low and the number of stops would double when delivering directly from the NDC. This involves extra costs, but there are also practical objections such as driving time restrictions and noise complaints when there are more stops at outlets. Therefore flow types 0-2-1a, 0-0-2 and 2-0-1a can be used, while flow type 0-2-0 is excluded from the flow type options. These flow types are also most comparable to the current set of flow types, which makes it a realistic model.

Current scenario B: four regional and one national distribution center

This scenario is very similar to the previous one. The only difference is that constraints [C.4] and [C.5] are no longer applied. This scenario can be achieved by changing the capacities of the current DCs.

Future scenario C: three regional and one national distribution center

As this model calculates the costs for handling and transport, Jumbo is interested in knowing what these costs are when there are three instead of four regional distribution centers. In this scenario capacity constraints [C.4] and [C.5] are no longer applicable. One RDC is deleted from the set of distribution centers and the outlets are reassigned based on shortest total distance with the constraint that the remaining three RDCs handle at most 40% of the total volume each, to require a more or less equal capacity among RDCs.

Future scenario D: three regional distribution centers

Previously it was shown that when volume is split over a NDC and RDCs, the utilization of carriers decrease and there are extra costs involved for inter-DC transportation or direct delivery from the NDC. This future scenario assumes there is no NDC, but only three RDCs. Again, capacity constraints [C.4] and [C.5] are no longer applicable. In section 5.7 it was argued that extra waste costs can be neglected as the difference among flow types is relatively small. The extra safety stock that is required when keeping inventory downstream in the supply chain is limited. However, in the aforementioned scenarios there was always a NDC which can be used

in case of exceptions. Especially items with low sales volumes and a short shelf life (days-fresh) are tricky to keep at multiple RDCs. Section 5.7 indicates that the effect on waste costs is limited. However, not having the option to keep stock at the retailer's NDC might violate the functional requirement of delivering goods to outlets at least as fresh as currently is the case. For these tricky items usually the NDC is used to overcome these negative effects and to prevent the RDCs from having too many SKUs. In this scenario the retailer has no back-up for tricky items. The solution here is to oblige suppliers with these type of products to deliver via XD-TR, in order to benefit from the pooling effect at the supplier and to prevent too many SKUs at the retailer's DCs. These are usually suppliers that deliver convenience products. Modelling in this way is much more realistic than assuming all items can potentially be held at the RDCs.

Case packs per box

The set of suppliers that are restricted to XD-TR usually have very small case packs, meaning that the metric volume was quite low. The reason for this is that for these type of items the number of consumer units per case pack is low, most often equal to one. As these products are sold scantily and have a short shelf life, Jumbo wants to allow outlets to order these products one at a time. When these suppliers are restricted to XD-TR, there is a potential for improvement without changing the number of consumer units per case pack. As these suppliers deliver multiple products, they can be stacked into a single box such that a box can carry multiple case packs. This is also current practice for a number of suppliers currently delivering via cross-dock and transito. Obviously, outlets should be able to handle these bigger boxes with multiple SKUs in it. However, as a supplier usually supplies within one family group, it is assumed this will be possible without extra costs at the outlets. While doing so, the number of boxes that need to be handled at the RDCs for XD-TR will be reduced.

For this scenario, the item characteristics of suppliers restricted to XD-TR are altered. The number of case packs remain the same, while the number of case packs per box increases and the size of boxes increases proportionally. In order to reap the benefits from this approach, one needs to be sure that outlets order sufficiently large volumes that boxes are full. Otherwise smaller boxes are required to prevent a low utilization of boxes.

Future scenario E: one national distribution center

As some retailers use a single NDC to distribute their fresh assortment, Jumbo would like to know what the costs and benefits are. Distances are relatively short in the Netherlands, such that direct delivery from NDC to outlets might be cost efficient despite the extra transportation costs to outlets. Especially because of lower fixed facility, inventory and waste costs, while operational costs (transport and handling) are higher. The utilization of pallets, carriers and trucks is no longer an issue. Neither is the number of stops at outlets, because the NDC is the only point from where outlets get supplied their perishables. Note that non-perishables can still be supplied in a different way, for instance via RDCs. However, when the total volume of the fresh assortment is delivered via the NDC, the average number of stops per trip is 1,7. This suggests volume is large enough to operate completely independent from the non-perishable assortment.

6.5.2 SCENARIO COMPARISON

In this section, the scenarios described above are compared. For all scenarios the flow type selection is optimized per supplier, using flow types that are currently not available such as 2-0-1a. However, the goal of this section is to provide insights in network changes from a flow type selection perspective. Table 6.3 shows for each scenario what the number of suppliers is within a certain flow type. The former sections have shown that the options are stock NDC (0-2-0 or 0-2-1a), stock RDC (0-0-2), or XD-TR (2-1a-0 and 2-0-1a).

Flow type selection comparison

When comparing scenario B with scenario A, it can be observed that the absence of a capacity restriction makes the model choose to keep stock at the RDCs more often. Fewer suppliers deliver via the NDC. It is not expected that this decrease in inter-DC volume will lower the

average utilization of trucks, as there are still more than seven full truckloads needed per day from the NDC to the smallest RDC.

Scenario B and C are very similar. Apparently closing a RDC has little influence on the optimal flow type selection of suppliers. One would expect more suppliers will deliver to the RDCs as there are fewer RDCs, but this prediction is not true. In fact, even a small shift from 2-0-1a to 0-2-1a can be noticed for a few suppliers due to lower inter-DC transportation costs with fewer RDCs.

Table 6.3: Number of suppliers per flow type for four scenarios

	Stock NDC	Stock RDC	XD-TR
Scenario A	28	54	18
Scenario B	14	78	8
Scenario C	16	78	6
Scenario D		79	21
Scenario E	96		4

The suppliers keeping stock at the NDC in scenario C switched to delivering via XD-TR in scenario D, because the NDC is not used anymore. Remember that a number of suppliers were restricted to flow type 2-0-1a to make sure freshness requirements were not violated. If this restriction is relaxed, the model is similar to the base model in Table 6.2, where only 8 suppliers deliver via XD-TR. However, the costs are roughly the same as the difference is only 0,3%. It is mainly a shift in handling costs from supplier to retailer when fewer suppliers deliver via XD-TR. In scenario E most suppliers should deliver at the NDC, because the *Ratio_s* denoted in formula [6.1] is lower compared to its RDC-counterpart. The relatively high pallet utilization makes delivery at the NDC most attractive for most suppliers. For this scenario suppliers were only allowed to choose between two flow types: 0-2-0 and 2-1a-0. Almost all suppliers should deliver via 0-2-0 as full pallet deliveries occur more frequently. An interesting observation is that when 2-1b-0 is included in the flow type options, some suppliers switch from 0-2-0 to 2-1b-0. Due to higher pallet utilization, a PTZ-operation becomes profitable for suppliers with high volumes per SKU. We would like to refer to the discussion in section 6.2.9 on a PTZ-operation. Such an operation is more cost efficient than ‘stockless for supplier’-flow types when sales volumes are high. In that case, one should be very careful with conclusions regarding 2-1b-0, as it is unknown how much ‘storing’ is required. Besides, the cost difference between including or excluding PTZ is minimal (less than 0,5%). Therefore, in order to compare this scenario to others, only 0-2-0 and 2-1a-0 are considered.

Cost comparison

The following two figures show the cost differences between the scenarios. Removing the capacity restrictions has little influence on the total costs. Only a shift in costs can be noticed from supplier to retailer as more picking activities take place at the retailer in this situation. Closing a RDC is beneficial for both handling and transport, but mainly for transport. Fewer carriers need to be handled and transported. Despite somewhat longer average distances from RDCs to outlets, the transportation costs are lower due to fewer carriers. Figure 6.10 shows that these benefits are for both supplier and retailer. Suppliers benefit because they deliver to fewer RDCs. The retailer benefits from fewer carriers, but also less inter-DC transportation costs as goods are shipped to only three RDCs. Total supply chain-wide operational costs decrease by approximately 5%. However, it should be noted that this requires more capacity for the RDCs, which would require significant investments. On the other hand, one RDC will not be used anymore, which could lead to cost savings on fixed facility costs.

Scenario D has the lowest operational costs (approximately 10% less than scenario B). Compared to scenario C, suppliers make more handling costs as picking activities take place at the supplier for about 20% of the suppliers. Also, transportation costs for the suppliers are a bit higher, because none of the suppliers deliver to the NDC anymore which was very favorable for supplier transport costs. However, compared to scenario B the total costs for the supplier are

more or less the same. The retailer mainly profits from lower transportation costs, as there are no inter-DC deliveries needed from NDC to the RDCs.

Scenario D is very different from the other scenarios as only a single DC is used. This is very beneficial for the suppliers, as they only have to deliver to the NDC and only a few suppliers apply XD-TR. Therefore, most handling (e.g. picking) costs are made downstream in the supply chain at the retailer. As expected, the transportation costs at the retailer increase significantly as well, as outlets are delivered directly from the NDC, more kilometers are travelled.

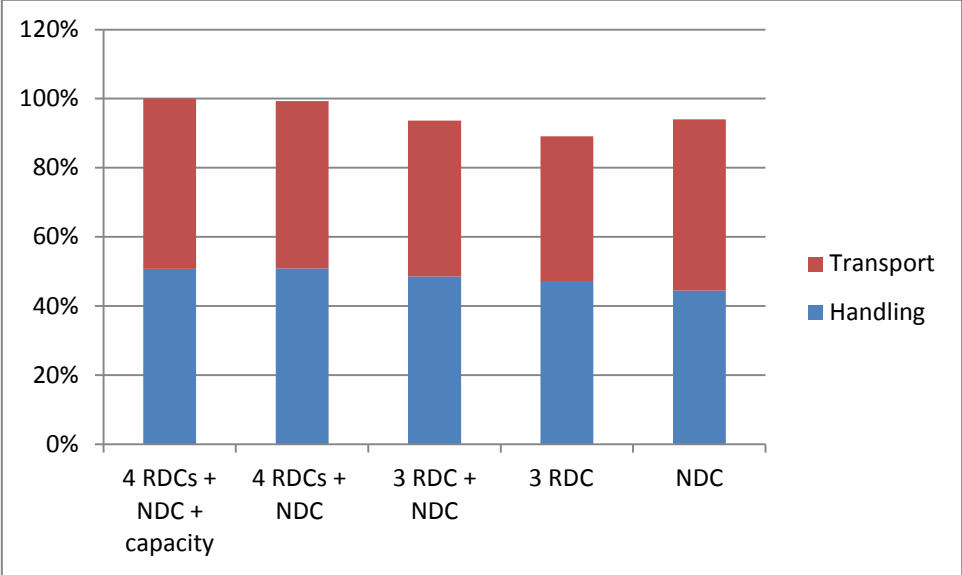


Figure 6.9: Total costs split over transport and handling for each scenario

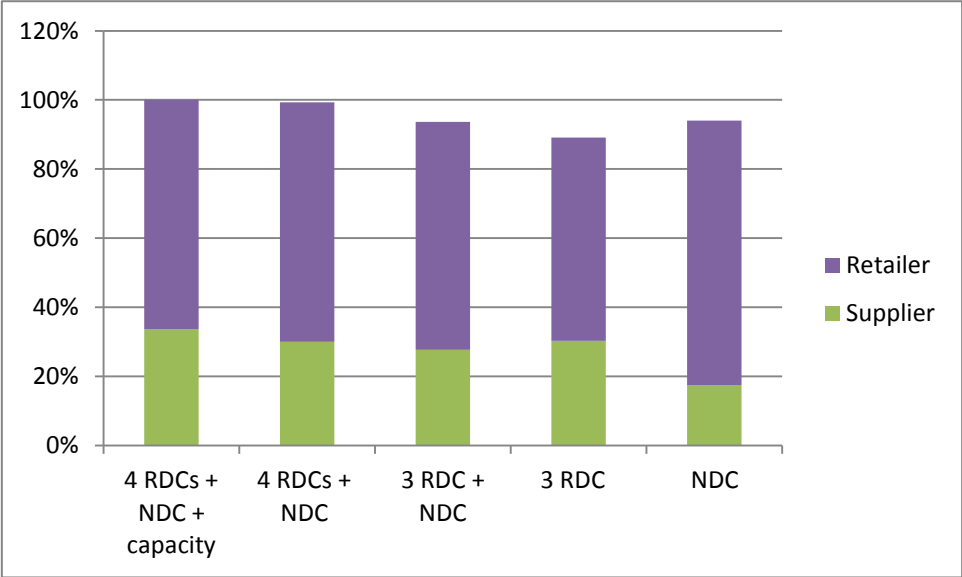


Figure 6.10: Total costs split over supplier and retailer for each scenario

6.6 DISCUSSION

Stockless for supplier flow types

Keeping stock at the retailer rather than at the supplier is usually most cost efficient. Although this model assumes suppliers send their products immediately after production to the retailer DC, this might not always be the case. However, the sensitivity analysis in section 6.4 showed when the number of batches per week (bpw_s) is set equal to the number of deliveries per week ($dpw_{f,t,s}$), the majority of the suppliers should still deliver via a 'stockless for supplier'-flow type.

Cross-dock/transito and transito on pallets

Regarding the 'stockless-for-retailer'-flow types, it can be concluded that the hybrid flow type of XD-TR is very promising as it performs better than pure cross-docking and pure transito. The output of scenario A and B provides a list of suppliers for which most often this flow type is beneficial. These suppliers usually have either many SKUs, multiple case packs per box, big boxes, medium to high sales volumes, or a combination of these characteristics. Also, there are possibilities to further improve this by increasing the box sizes and by placing multiple case packs (SKUs) in a box, as suggested in section 6.5.1.

As mentioned before, the utilization of pallets and carriers has a big impact on total costs. It is also suggested to use bigger boxes in order to decrease the number of boxes and the handling activities related to that. A disadvantage of XD-TR is still the relatively low utilization of space. For the part from supplier to DC, this might be improved by supplying big outlet-specific boxes (crates) on pallets. This will increase the number of case packs that are carried in a truck and also reduces the number of handling activities related to either moving a pallet or a carrier. Furthermore, the possibility exists to automate the process of receiving and distributing outlet-specific boxes that are received on pallets. The process from DC to outlet can still be executed on carriers. Again, the disadvantages of bigger boxes should also be considered. For instance the possible extra handling in outlets due to the many SKUs in a box and the possibility of lower utilization of boxes as volumes to outlets could be insufficient to fill a big box.

Put/pick-to-zero

Section 6.3 suggests that a PTZ-operation is not cost efficient to implement at the RDCs. The split of volume increases the number of pallets to be handled significantly such that other flow types such as 0-0-2 or 2-0-1a are less costly. However, future scenario E (section 6.5.1, only a single NDC) shows this operation might still be beneficial due to fewer dropping points for the supplier. Again, this flow type requires a high sales volume per SKU to be cost efficient. In that case one can question whether or not the 'storing' activity can still be excluded from the cost comparison. Besides, it is unlikely that the assortment of Jumbo will shrink. More likely the number of SKUs will increase, which makes this flow type even more expensive.

Future scenarios

In general, having both RDCs and a NDC involves extra inter-DC transportation and lower carrier utilization. One reason for keeping stock at the NDC is to benefit from the pooling effect. Also, for every SKU a picking location is reserved, which would increase the facility costs when keeping all products at the RDCs. Currently capacity is also a reason why the NDC is used, as the RDCs simply do not have enough capacity to keep all the inventory. Section 0 has shown that a scenario with three RDCs, without a NDC, results in the lowest operational costs. It should be noted that this includes only handling and transport. It is difficult to judge whether fixed facility and inventory costs will increase or decrease. On the one hand, one RDC and the NDC will be closed. On the other hand, the capacity of the remaining three RDCs need to increase. Not only because of the extra volume, but also because there are likely to be more picking-locations required as there is no more option to keep stock at a central NDC. Furthermore, some suppliers need to be forced to apply XD-TR to assure freshness maintains or improves compared to the current situation. Another solution to this problem could be to introduce a carrousel, suggested by Van der Vlist (2007). In this system, all RDCs function partly as a NDC. By doing so, the assortment that would normally be stored at the NDC is now split over multiple RDCs. Inter-DC shipments (in a carrousel) will allow for goods to move from one RDC to another. However, this alternative solution is not included in the model and requires further research. When investigating the possibilities for a carrousel, it is recommended to include suppliers in the analysis. As for some product families (e.g. dairy) suppliers tend to be located near to each other. Appendix E shows a map of where the biggest suppliers for four product families are located. This shows the close proximity of some suppliers within a product family.

Using only a single NDC (scenario E), is mainly beneficial for the supplier. The retailer is confronted with extra costs. It would require a lot of effort to gain back the benefits that arise for

suppliers. Besides, an enormous DC is required in order to keep more or less all items on stock. However, the advantages are clear. All costs (handling, transport to the NDC, waste, fixed facility, inventory and overhead) are likely to decrease or at least remain at their current level. Except for transportation to the outlets, which will increase. On the other hand, the model assumes backhauling activities are not done because return freight needs to be returned to the NDC. It is likely that at least some backhauling activities will be executed to reduce total transport costs due to the relatively long distances which make backhauling attractive.

The future scenario that is closest to the current network is scenario C. It assumes three RDCs and one NDC. This scenario has similar cost savings as scenario E, while it is much less disruptive for the supply chain. Besides, this could be a stepping stone to scenario D, which is the most cost efficient in terms of handling and transport costs.

7 IMPLEMENTATION

As this is a strategic study, the model contains a number of assumptions on how the operational process is performed. In reality adaptations to these processes are required in order to make the processes assumed in this study realistic. This chapter describes what actions are needed and how this model can be used. A split is made between short-term and long-term implementation issues.

7.1 SHORT TERM IMPLEMENTATION ISSUES

Administratively allow XD-TR

This study has shown that a combination of cross-dock and transito increases the utilization of carriers compared to pure cross-docking or pure transito. Unfortunately current IT-systems do not allow XD-TR. Only outlet-specific carriers can be received at the RDCs. Not only administratively, but also physically there is not much experience in receiving carriers containing multiple outlets. A pilot could be helpful to uncover the operational issues arising when implementing XD-TR. Also, allow transito on pallets as it is expected that this could be a very interesting flow type for some suppliers and it is possible to automate such a process.

Facilitate stockless for supplier flow types

In the conceptual model it was discussed that in order to increase or maintain freshness and decrease costs, the supply chain should only contain one inventory point. The analysis showed that in most cases 'stockless for supplier'-flow types are the best flow types. Currently many suppliers also have their own inventory, such that there are two points of inventory. One way to prevent this and to control the supply chain is to implement vendor managed inventory (VMI). This control structure allows suppliers to manage the inventory at the retailer. By doing so, they can plan production batches based on sales forecasts and synchronize distribution to the production schedule.

Separate logistics cost from the purchase price

This study has included primary, secondary and tertiary costs. So the logistics costs made at the supplier are also included in the optimization model. In line of what Van der Vlist (2007) suggests, negotiations on logistics costs and purchase price should be separated. This model can be used to estimate the logistics costs made by a supplier, which can be used in the negotiation. Furthermore, when separating logistics costs, more knowledge can be obtained about the supplier costs. This knowledge can also be used to make a better consideration on where activities should take place, or for instance to find opportunities for backhauling.

Optimize current suppliers' flow types

This model has shown that given the current network, only three flow types (i.e. 0-2-1a, 0-0-2 and 2-0-1a) should be considered. By investigating the suppliers that are eligible for a different flow type, the optimal flow type per supplier can be identified. This model can be used to highlight these eligible suppliers, but can also be used as a basis to model handling and transport costs. On a supplier-specific level, input parameters and assumptions should be checked and possibilities to combine multiple flow types should be investigated. Furthermore, supplier-specific characteristics should be considered when these are not included in the model.

7.2 LONG TERM IMPLEMENTATION ISSUES

Stepwise implementation towards a new network

Assuming the short-term implementation issues have been overcome and suppliers deliver via the most suitable flow type, distribution network adjustments might disrupt the optimal flow type selection. Designing an optimal distribution network is out of scope for this study. However, this research provides insights on how distribution flow types should change when the distribution network changes. Consider the long-term possibility to move from scenario B (4 RDCs + NDC), to scenario C (3 RDCs + NDC) to scenario D (3 RDCs). This model is not suitable to make these decisions, as it requires additional analysis on other costs as well. For instance the

required investments. Nevertheless, this model can be used as input for the handling and transport costs. Besides, it shows how optimal flow type selection changes when these network changes would happen. This model can also be used to model other network configurations, such as networks with two DCs.

8 CONCLUSIONS AND RECOMMENDATIONS

This chapter will conclude this master thesis. The next section answers the main research question and discusses the most important findings. Furthermore, it lists the contribution of this research both on academic and practical level. Finally, the recommendations, limitations and suggestions for future research will be discussed.

8.1 CONCLUSIONS

This is a strategic study on distribution flow type selection for perishables. It facilitates long-term decision making for determining and designing physical distribution structures between suppliers and retail outlets. According to the definition of Hübner et al. (2013) it creates structures for distribution modes, such as cross-docking or warehouse delivery. The research question reads as follows:

What are the best distribution flow types for fresh products in a retail supply chain such that overall costs are lowest, while maintaining or improving freshness at the outlet with a predefined service level?

This study has created structures for distribution modes, or in other words: it has created and evaluated distribution flow types. Three flow types were identified as most important. These are 'stockless for supplier'-flow types and a 'stockless for retailer'-flow type. The former consists of two flow types. Suppliers deliver immediately after production to the NDC (0-2-1a) or to the RDC (0-0-2). It should be noted that in reality a supplier might still hold some inventory if perishability allows him to, such that 0-0-2 in practice is sometimes 2-0-2. However, this study assumed direct delivery after production in order to maintain or increase freshness. For most suppliers flow type 0-0-2 (keeping stock at the RDCs) is the best flow type in terms of total supply chain costs. Suppliers with slow moving fresh should deliver at the NDC. For fresh products the delivery frequency (or number of batches per week) should be high in order to prevent waste. This, in combination with low sales volumes make it very expensive to split the delivery over multiple RDCs. Hence, delivering at the NDC is better. Regarding the 'stockless for retailer'-flow types, XD-TR at the RDC (2-0-1a) performs well. Especially for suppliers that usually have either many items, multiple case packs per box, big boxes, medium to high sales volumes, or a combination of these characteristics. Also, there are possibilities to further improve this by increasing the box sizes and by placing multiple case packs (SKUs) in a box. Furthermore, this study has concluded that a PTZ-operation is not cost efficient at the RDCs due to the high number of pallets that need to be handled. Pick-to-zero might only be interesting when using a single NDC (scenario E), but the cost savings compared to excluding pick-to-zero is very small. Besides, these cost savings arise under tricky assumptions, for instance the assumption that no storing activities will take place while for high volumes this is rather unrealistic.

In order to maintain or improve freshness (and minimize waste), the set of flow types is limited (all flow types only have one stock point). Most scenarios include a NDC, which is considered sufficient to at least keep freshness at current level. When no NDC is used, which is very beneficial in terms of costs, it requires more XD-TR suppliers to keep freshness at or above the current level.

During the development of the conceptual model, the functional requirements of the system were determined based on the main research question. One of the factors that was included was the service level. As explained in section 4.3, the distribution system that is designed should be able to perform at least at the current level in terms of delivery frequency and lead time, meaning that a maximum lead time of 24 hours is assumed. One could also say that the service to the outlets should be equal to the current situation, so in this study no optimization on delivery frequencies or lead times is done. The model in this research allows for maintaining current service levels by fixing the lead time and review period. Nevertheless, in section 6.2 and the sensitivity analysis, a theoretical exercise is performed to see what the effect would be when lead time increases. By doing so, the delivery frequency can be reduced for 'stockless for

retailer'-flow types, which is beneficial for these flow types. The required safety stock is obviously dependent on the location of the inventory: at the supplier, the NDC or the RDCs. However, the safety stock decision is a tactical issue on supply chain control structures, as discussed in section 2.1.5. Therefore this is left out of scope and it is considered that there is no difference in service level among flow types. One should keep in mind that there might also be practical issues regarding service levels. Van der Vlist (2007) argues that in 'stockless for retailer'-flow types there is a lot of time pressure. Evidently, products need to be picked, packed, loaded, consolidated at the retailer DC and sent to the outlets. All these activities should be performed within 24 hours. This study assumes this is possible.

Network

This model has also shown that optimal flow type selection depends on the distribution network. When having only one NDC it is cheapest to apply the 'stockless for supplier'-flow type (0-2-0). With only three RDCs, XD-TR is required for some suppliers and is cost efficient. The latter scenario (scenario D) is the cheapest in terms of handling and transport. Furthermore, it is more realistic than having only one NDC. Besides, this scenario is able to go to this situation gradually by going from scenario B (four RDCs + NDC) to scenario C (three RDCs + NDC) to scenario D (three RDCs). These insights facilitate better strategic decision making on network structures. Furthermore, these are only a few scenarios functioning as an example. With a few adaptations to the model and the input parameters it can also be used to model for instance a network with two RDCs.

Contributions

From an academic perspective, flow type selection has been discussed in several papers and master theses. Van den Heijkant (2006) studied the flow type selection problem by comparing direct store delivery and central warehousing at METRO Cash & Carry Netherlands. Bovend'eerd (2010) did a similar master thesis at the same company in Germany and included the cross-docking option. A master thesis that deals with a perishables assortment is that of Gerbecks (2012). However, his study deals with a limited number of flow types, particularly for e-commerce and is not explicit in the process from supplier to retailer DC. The most comprehensive research on flow types is Van der Vlist (2007), who considers many variants from supplier to retail outlet and takes into account supplier distribution to DCs, cross-docks or outlets. However, his research does not explicitly consider the perishable assortment and the distinction between NDC and RDC delivery is not incorporated in the total supply chain from supplier to outlet. In accordance with Akkerman et al. (2010), it can be concluded that there is only a limited number of contributions on food supply chain designs in terms of distribution flow type selection. Even though some papers included perishability, only a few studies made a specific contribution for the food supply chain by including product quality in their models (e.g. Zhang et al. 2003; Blackburn & Scudder 2009; Van der Vorst et al. 2009). These papers usually dealt with either the location-allocation problem or with supply chain control structures and not explicitly with flow types.

First of all, this study contributes to scientific literature by presenting a very general way to model a supply chain network from supplier to outlet. The conceptual model presented in Figure 4.1 can be used in many retailing environments, not only perishables. Compared to Van der Vlist (2007), the conceptual model in this master thesis also includes the distinction between NDC and RDC by introducing tertiary distribution. Both Van den Heijkant (2006) and Bovend'eerd (2010) dealt with non-perishables and considered only a few flow types. This study evaluated many more flow types, also distinguishing between central and regional warehousing. Furthermore, this master thesis dealt with fresh products and the design was adapted to that. For the temperature-controlled assortment of supermarkets, which are usually perishable, this study has provided strategic insights in supplier and product characteristics and the corresponding optimal flow type. Finally, this study not only has created new distribution flow types (XD-TR), it has also excluded flow types from further analysis (PTZ).

For Jumbo this study is helpful in a number of ways. It provides conceptual insights in distribution flow type selection decisions and its most important parameters. For instance, it shows that some flow types are usually not cost effective (e.g. PTZ) and do not deserve much more attention in the future. Also, it gives suggestions for new flow types (e.g. XD-TR, transito on pallets etcetera). This study also provides concrete examples of suppliers that should be investigated in more detail as their flow type might not be optimal. Finally, it shows what the effect is on the optimal distribution flow type when the distribution network changes and how this influences handling and transport costs for both supplier and retailer. By this, more sophisticated strategic decision making on network questions can be done. It also includes estimated logistics costs for suppliers, which can be used in negotiating with suppliers.

8.2 RECOMMENDATIONS

As this research has provided strategic insights on distribution flow type selection for perishables, there are a number of recommendations for Jumbo which are listed here in this section.

- First, facilitate a flow type such as XD-TR. Also let transito on pallets be possible, although it might not immediately be implemented. Cost savings can be expected immediately for the current transito suppliers. This will also allow possible growth in assortment (number of SKUs) as costs do not depend on the number of SKUs for this flow type..
- Do not implement a put-to-zero operation. For most suppliers this is not cost efficient. Besides, put-to-zero requires an operation that is only suitable for put-to-zero. It will not be worthwhile to implement such an operation.
- On the other hand, pick-to-zero might be interesting for some suppliers or SKUs. As flow types 0-2-0 and 0-0-2 have a quite similar process as flow types 2-1b-0 and 2-0-1b (pick-to-zero), Jumbo might consider to use them simultaneously for some suppliers. It can be decided on SKU-level which of the two flow types is best and thereby trying to prevent the 'storing' activity which is present when using flow type 0-2-0. When an increase in lead time is accepted for some products, pick-to-zero becomes more interesting as it can be implemented concurrently with 'stockless for supplier'-flow types. However, pick-to-zero most often costs more than 'stockless for supplier'-flow types under the circumstances in this study. Therefore the aim should be to improve the supply chain via 'stockless for supplier'-flow types, rather than via pick-to-zero.
- Focus on implementing 'stockless for supplier'-flow types in collaboration with suppliers. These flow types are generally most cost efficient. Besides, they are quite similar to the traditional flow types with two stock points.
- Use the list of suppliers eligible for a flow type change to do an in-depth investigation on supplier-level. Input parameters and assumptions should be checked and possibilities to combine multiple flow types should be investigated. Furthermore, supplier-specific characteristics should be considered when these are not included in the model.
- Separate logistics costs from purchase price. By doing so, more knowledge can be obtained about the supplier costs. This knowledge can also be used to make a better consideration on where activities should take place, or for instance to find opportunities for backhauling. Van der Vlist (2007) provides practical suggestions on how these negotiations can be done.
- When changing the distribution network, keep in mind that optimal flow types change. This model can be used to show the effects in terms of handling and transportation costs. Furthermore, this study shows that a network with three RDCs is most cost efficient for supply chain-wide transportation and handling costs. It is also recommended to investigate the possibilities for a carousel, where assortment-specific RDCs are used as NDCs. This decreases the costs for suppliers, although inter-DC transportation costs increase. Appendix E provides additional information on this topic.

8.3 LIMITATIONS

During the construction of the model a number of assumptions have been made which are limitations of the model. First of all, only transport and handling costs have been included. Fixed facility, inventory and waste are not. Especially the latter exclusion is questionable when considering this research focusses on perishable items. However, section 5.7 has indicated that differences in waste are very small given the restricted set of flow types. Besides, the number of batches per week is based on the perishability of products, such that extra costs due to the short shelf lives are implicitly present as the required number of pallets increases with the production frequency. This immediately forms the next limitation. The assumption made in section 5.4.1 on the number of batches per week is very general. On the other hand, a sensitivity analysis showed that this does not significantly change the results. Only on supplier-specific level there are a few suppliers that will be more inclined to supply via XD-TR when the production frequency is increased (i.e. bpw_s is set equal to $dpw_{f,t,s}$). Another supplier-specific limitation is the assumption that a supplier is always able to deliver within a lead time of 24 hours, also when delivering via XD-TR. Finally, it is assumed that a supplier can only choose one flow type, while for some suppliers with a varying assortment it might be interesting to deliver both at NDC and at RDCs. This is also current practice, but this option is not included in the model. This paragraph contains the most important supplier-specific limitations. The others are listed in section 5.2.

Another important limitation is the estimated costs for primary distribution, which includes all handling and transportation costs from supplier to DC. Unfortunately we were unable to validate these costs. Nevertheless, on a retailer-level the base costs and cost drivers were validated, which makes the estimated costs for primary distribution also quite accurate.

8.4 SUGGESTIONS FOR FUTURE RESEARCH

This is one of the first studies on distribution flow type selection of the temperature-controlled assortment of supermarkets. Future research can build on this model by allowing for suppliers to deliver via multiple flow types. For instance a combination of 0-2-0 and 2-1b-0 or applying transito on pallets might be interesting. Furthermore, from a network perspective more network types can be investigated. For instance the network suggested by Van der Vlist (2007) which uses a carousel to split the volume of the NDC over RDCs. Finally, this study forms an excellent basis to determine optimal flow type selection of non-perishable suppliers (i.e. ambient products). With a few different emphases this model can be redesigned to function as a flow type selection tool for non-perishables as well.

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